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# ASTRONAUTICS INFORMATION

LITERATURE SEARCH NO. 149

MECHANICAL PROPERTIES  
PENETRATION DEPTH, AND  
RESIDUAL MAGNETISM  
IN SUPERCONDUCTORS

JET PROPULSION LABORATORY  
CALIFORNIA INSTITUTE OF TECHNOLOGY

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**ASTRONAUTICS INFORMATION**

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**MEISSNER EFFECT, PENETRATION DEPTH,  
AND RESIDUAL MAGNETISM IN  
SUPERCONDUCTORS**

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## FOREWORD

A survey was made of the periodical and report literature on the subjects of Meissner Effect, Penetration Depth, and Residual Magnetism in Superconductors, from both the theoretical and experimental standpoints, covering the period from January 1948 to July 1959.

This compilation was made as an aid to personnel at the Jet Propulsion Laboratory in the development of instrumentation.

Sources used were JPL Library Additions, November 1955 through July 31, 1959, *Nuclear Science Abstracts (NSA)*, *Physics Abstracts (PA)*, and *Chemical Abstracts (CA)*. The abbreviations in the *Chemical Abstracts* are the standard abbreviations used by that service.

Abstracts are arranged alphabetically by author in each section.

## **PREFACE**

The technical staff of the Jet Propulsion Laboratory library is engaged in an extensive literature searching program covering subjects selected by Laboratory engineers and designed to meet their individual needs. Searches considered to be of interest to persons working in the field of astronautics will be published for distribution to interested organizations.

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## I. THEORETICAL

**1. CONFERENCE ON CRYOGENICS,  
SCHENECTADY, NEW YORK  
October 6-7, 1952**

This report is an expanded collection of papers on cryogenics and related topics, presented at a conference sponsored by ONR and NSF. Subjects covered include the structure, wave propagation, heat transfer, and flow characteristics of superfluid  $\text{He}^3$ ; second-sound properties below  $1^\circ\text{K}$ ;  $\text{He}$ -film transport over various materials;  $\text{He}^3$ - $\text{He}^4$  heat separation; specific heat and thermodynamic properties of materials at liquid- $\text{He}$  temperatures; demagnetization and liquefaction techniques; resistance of materials at low temperatures; superconductivity and superconductive properties of materials at liquid- $\text{He}$  temperatures. (NSA, v. 7, #6506)

**2. LOW TEMPERATURE BIBLIOGRAPHY FOR  
THE FIELD OF CRYOGENICS  
October, 1952  
A. D. Little, Inc., Mechanical Division  
Bibliography**

Abstracts are given of reports concerning the field of cryogenics. The abstracts are arranged by subject.

**3. LOW TEMPERATURE BIBLIOGRAPHY FOR  
THE FIELD OF CRYOGENICS  
Received JPL: May 28, 1957  
A. D. Little, Inc., Mechanical Division  
Bibliography, Supplement 1**

**4. NEW WORKS IN PHYSICS  
*Vestnik Akademii Nauk, SSSR*, v. 27, no. 4, pp. 110-111,  
1957 (in Russian)**

A review is given of reports presented to the Physics and Mathematics Conference, February 21, 1957. The relationship of atoms of various elements to electrons and the effects of such relationship on the outer structure of the electron shell was discussed by V. M. Dukel'skii: investigations of new semi-conductors of complexes with sphalerite and wurthite were described by N. A. Goryunova; the theory of molecular force attractions between solid bodies, and the theory of magnetic properties of superconducting alloys not based on macroscopical

heterogenetics were discussed by E. M. Lifshits and A. A. Abrikosov, respectively. (NSA, v. 11, #8036)

**5. PROCEEDINGS OF THE INTERNATIONAL  
CONFERENCES ON THE PHYSICS OF VERY  
LOW TEMPERATURES  
September 6-10, 1949  
Massachusetts Institute of Technology,  
Physics Department  
Meeting 1949**

**6. PHYSICS DIVISION QUARTERLY PROGRESS  
REPORT FOR PERIOD ENDING MARCH 20, 1952  
Issued October 22, 1952  
ORNL-1289**

Progress is reported on the following projects: energy spectrum of protons from  $\text{He}^3$  bombarded by  $\text{He}^3$ , energy spectrum of particles from  $\text{H}^3$  bombarded by  $\text{He}^3$ , proton bombardment of light elements, (p,n) thresholds in Ne, angular correlation of  $\gamma$  rays, K-shell internal conversion coefficient measurements, neutron-diffraction studies of superconducting elements, neutron-diffraction studies of some rare earths, total neutron cross sections at In resonance energy of 1.44 ev, specific heat of  $\text{Nd}(\text{C}_2\text{H}_3\text{SO}_4)_3 \cdot 9\text{H}_2\text{O}$  from 1 to  $2^\circ\text{K}$ , measurement of the weiss constant in  $\text{CuK}_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ , superconductivity of a Hf-Zr alloy, space distribution of ionization in a gas, neutron decay, neutron cross sections, theory of T + D reactions, and the parameterization of quantum electrodynamics. (NSA, v. 6, #6624)

**7. THE INTERACTION IN THE ELECTRON-  
LATTICE SYSTEM I. THE CORRESPONDENCE  
PRINCIPLE**

Abe, R.

*Busseiron Kenkyu*, no. 83, pp. 59-77, 1955

Mathematical and theoretical. The Fröhlich condition for the appearance of superconductivity is examined. (CA, v. 49, 13758d)

**8. CONTEMPORARY THEORY OF SUPER-  
CONDUCTIVITY**

Abrikosov, A. A., Khalatnikov, I.

*Uspekhi Fizicheskikh Nauk*, v. 65, pp. 551-591, 1958

A review with 21 references. (CA, v. 53, 4919i)

# 9. DETERMINATION OF THE VALUE OF THE DIELECTRIC CONSTANT AND NORMAL CONDUCTIVITY OF SUPERCONDUCTORS

Abrikosov, A. A.

*Doklady Akademii Nauk, SSSR*, v. 86, no. 1, pp. 43-46, 1952 (in Russian)

General formulae are given which enable the conductivity  $\sigma$  of the "normal" electrons and the effective dielectric constant  $\epsilon$  to be deduced from measurements of the surface impedance of a superconductor in a high frequency field. The calculations are based on the theory of Reuter and Sondheimer (Abstract 180). It is pointed out that the surface impedance of a thin film involves  $\sigma$  and  $\epsilon$  in a simpler way than for bulk metal, so that measurements on thin films might provide a more reliable determination of  $\sigma$  and  $\epsilon$ . (PA, v. 56, #5483)

# 10. INFLUENCE OF SIZE ON THE CRITICAL FIELD OF SUPERCONDUCTORS OF THE SECOND GROUP

Abrikosov, A. A.

*Doklady Akademii Nauk, SSSR*, v. 86, no. 3, pp. 489-492, 1952 (in Russian)

The phenomenological theory of Ginzburg and Landau (Abstract 89) contains a dimensionless parameter  $\kappa = \sqrt{2} (e/\hbar c) H_c \lambda^2$  ( $H_c$  = bulk critical field,  $\lambda$  = penetration depth into bulk specimen). The theory of the critical field of thin films had previously been worked out only for  $\kappa < 1/\sqrt{2}$  (superconductors of "the first group") and is now extended to cover  $\kappa > 1/\sqrt{2}$  (superconductors of "the second group"). It is suggested that thin tin and thallium films deposited at low temperatures may be superconductors of the second group and some support for the theory is found in measurements on such films by Zavaritskii (see abstracts in Sec. II-C). (PA, v. 56, #5475)

# 11. MODERN THEORY OF SUPERCONDUCTIVITY

Abrikosov, A., Kholatnikov, I.

*Uspekhi Fizicheskikh Nauk*, v. 65, pp. 551-591, August 1958 (in Russian)

The modern theory of superconductivity based on the copper effect and Bogolyubov methods is presented. The part played by electron Coulomb interactions is explained, though an accurate solution of the problem was not found. However, it is felt that the attenuating effects of Coulomb repulsion appear in the presence of electron

interactions through a phonon field. Results based on the principle of the new theory obtained for the behavior of superconductors in high-frequency electromagnetic fields are described. (NSA, v. 13, #2526)

# 12. ON THE THEORY OF SUPERCONDUCTION ALLOYS. I. THE ELECTRODYNAMICS OF ALLOYS AT ABSOLUTE ZERO

Abrikosov, A. A., Gor'kov, L. P.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 35, pp. 1558-1571, December 1958 (in Russian)

A theory of superconductors containing impurities at zero temperature is presented. The dependence of the penetration depth on the impurity concentration is examined supposing the concentration to be small. The electrodynamic equations in alternating field were obtained for superconductors having the electron-free path smaller than the correlation length. (NSA, v. 13, #4920)

# 13. BARDEEN'S THEORY OF SUPERCONDUCTIVITY AND THE $f$ -SUM RULE

Adams, E. N., II

Letter in *Physical Review*, v. 86, pp. 258, April 15, 1952

It is shown that on Bardeen's model the Landau-Peierls susceptibility is actually paramagnetic and would not, therefore, keep out the magnetic field. (PA, v. 55, #5795)

# 14. MAGNETIC SUSCEPTIBILITY OF A DIAMAGNETIC ELECTRON GAS: THE ROLE OF SMALL EFFECTIVE ELECTRON MASS

Adams, E. N., II

*Physical Review*, v. 89, pp. 633-648, February 1, 1953

An exact formula for the "steady" bulk susceptibility of a degenerate electron gas is derived. The deviations from the Landau-Peierls formula are studied for several situations in which the effective electron mass is small. It is concluded that, in any case for which the Landau-Peierls susceptibility differs from the Landau susceptibility, the total susceptibility differs from the Landau-Peierls susceptibility by an amount of the same order of magnitude. The magnitude susceptibility of solid Bi is discussed on a model developed by H. Jones. It is found that for several reasons, Jones's model requires major modification. A particular modification is suggested as a possible basis for a theory of the Bi susceptibility. Some implications of the conclusions are discussed in connection with Bardeen's

theory of superconductivity and the theory of the de Haas-van Alphen effect. (PA, v. 56, #2551)

# 15. CONDUCTION ELECTRON-MAGNETIC ION INTERACTION IN RARE EARTHS

Anderson, G. S., Legvold, S.

*Physical Review Letters*, v. 1, no. 9, pp. 322-324, November 1, 1958

It is suggested that the depression of the superconducting transition temperature  $T_c$  of La on alloying with rare-earth metals is due to changes in the effective electron-electron interaction,  $V$ , which may arise from exchange interactions between conduction electrons and magnetic ions. An empirical formula for  $V$  as a function of the concentration and spin of the solute atoms is substituted in the formula for  $T_c$  given by Bardeen, Cooper and Schrieffer. Good agreement with the experimental data is obtained. (PA, v. 62, #4622)

# 16. COHERENT EXCITED STATES IN THE THEORY OF SUPERCONDUCTIVITY: GAUGE INVARIANCE AND THE MEISSNER EFFECT

Anderson, P. W.

*Physical Review*, v. 110, no. 4, pp. 827-835, May 15, 1958

Discusses the coherent states generated in the Bardeen, Cooper, and Schrieffer theory of superconductivity by the momentum displacement operator  $\rho_Q = \sum_n \exp(iQ \cdot r_n)$ . Without taking into account plasma effects, these states are like bound Cooper pairs with momentum  $\hbar Q$  and energies lying in the gap, and they play a central role in the explanation of the gauge invariance of the Meissner effect. Long-range Coulomb forces recombine them into plasmons with equations of motion unaffected by the gap. Central to the argument is the proof that the non-gauge-invariant terms in the Hamiltonian of Bardeen, Cooper, and Schrieffer have an effect on these states which vanishes in the weak-coupling limit. (PA, v. 61, #5010)

# 17. NEW METHOD IN THE THEORY OF SUPERCONDUCTIVITY

Anderson, P. W.

*Physical Review*, v. 110, pp. 985-986, 1958

Next higher-order corrections to the Bardeen-Cooper-Schrieffer theory show that neglected collective and hidden plasmon effects reinforce the theory. (CA, v. 52, 16887b)

# 18. RANDOM-PHASE APPROXIMATION IN THE THEORY OF SUPERCONDUCTIVITY

Anderson, P. W.

*Physical Review*, v. 112, no. 6, pp. 1900-1916, December 15, 1958

A generalization of the random-phase approximation of the theory of Coulomb correlation energy is applied to the theory of superconductivity. With no further approximations it is shown that most of the elementary excitations have the Bardeen-Cooper-Schrieffer energy-gap spectrum, but that there are collective excitations also. The most important of these are the longitudinal waves which have a velocity  $v_F \{ \frac{1}{3} [1 - 4N(0)|V|] \}^{1/2}$  in the neutral Fermi gas, and are essentially unperturbed plasma oscillations in the charged case. Other collective excitations resembling higher bound pair states may or may not exist but do not seriously affect the energy gap. The theory obeys the sum rules and is gauge invariant to an adequate degree throughout. (PA, v. 62, #3509)

# 19. DEVELOPMENT OF THE STUDY OF SUPERFLUIDITY AND SUPERCONDUCTIVITY IN THE USSR

Andronikashvili, E. L., Tumanov, K. A.

*Uspekhi Fizicheskikh Nauk*, v. 33, pp. 469-532, 1947

Critical review; 132 references (CA, v. 43, 7765b)

# 20. ON THE PENETRATION OF A MAGNETIC FIELD INTO A SUPERCONDUCTOR

Avakyan, G. M.

*Journal of Experimental and Theoretical Physics, USSR*, v. 19, pp. 946-949, October 1949 (in Russian)

An approximate method of calculation based on the London's equation is described. (PA, v. 53, #2465)

# 21. THEORY OF ELECTRON PARAMAGNETIC RESONANCE IN SUPERCONDUCTORS

Azbel, M. Ya., Lifshits, I. M.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 33, pp. 792-794, 1957

The possibility of having paramagnetic resonance and selective transparency in superconductors was discussed. An English translation is given in *Soviet Physics JETP*, v. 6, pp. 609-611, 1958. (CA, v. 52, 10723a)

**22. DEBYE MODES AND SUPERCONDUCTIVITY**

Band, W.

*Physical Review*, v. 79, pp. 739-740, 1950

A crystal mass may conceivably be at so low a temp. that each domain contains nothing but the zero-point energy of its Debye modes. The crystal as a whole will still have non-zero entropy owing to the randomness of phase incoherence between the domains. These phase discontinuities will be responsible for residual resistance of the lattice to the elec. current. Because of the surface energy in the domains it can be shown that there exists a transition temp. below which the disorder due to phase incoherence gives way to order and phase coherence throughout the crystal. Such an order-disorder transition among the phases of the zero-point Debye modes might be at least in part responsible for supercond., and could conceivably account for the isotope effect recently reported. (CA, v. 44, 9757b)

**23. SUPERCONDUCTIVITY AND DEBYE MODES**

Band, W.

Letter in *Physical Review*, v. 79, p. 1005, September 15, 1950

If the temperature of the coherence-incoherence transition of phase domains of Debye modes is identified with the transition temperature  $T_c$  of a superconductor, a reasonable order of magnitude is obtained for  $T_c$ ; the observed variation of  $T_c$  with the square root of isotopic mass is also obtained. (PA, v. 54 #1064)

**24. CHOICE OF GAUGE IN LONDON'S APPROACH TO THE THEORY OF SUPERCONDUCTORS**

Bardeen, J.

Letter in *Physical Review*, v. 81, pp. 469-470, February 1, 1951

London's choice of gauge for the vector potential is derived from the principle that the Schrödinger equation must be invariant with respect to gauge transformations. (PA, v. 54, #5420)

**25. CRITERION FOR SUPERCONDUCTIVITY**

Bardeen, J.

Letter in *Physical Review*, v. 82, pp. 978-979, June 15, 1951

Consideration is given for distinguishing between interactions occurring in the normal phase and those giving rise to superconductivity. In the normal phase there is no

appreciable change in effective mass or in electrical properties; in the superconducting phase the electrical properties are similar to those of a metal with a small concentration of carriers of small effective mass. (PA, v. 54, #7905)

**26. FIELD VARIATION OF SUPERCONDUCTING PENETRATION DEPTH**

Bardeen, J.

*Physical Review*, v. 81, pp. 1070-1071, March 15, 1951

Pippard's observation that the penetration depth of a magnetic field into a superconductor depends little on magnetic field, is interpreted in terms of Bardeen's theory of superconductivity. In consequence, the assumed low-wave functions are little affected by a magnetic field and must extend over distances of at least  $10^{-4}$  cm. It is suggested that the transition temperature of superconducting particles will change when the size is reduced below  $10^{-6}$  cm. (PA, v. 54, #5421)

**27. GAUGE INVARIANCE AND THE ENERGY-GAP MODEL OF SUPERCONDUCTIVITY**

Bardeen, J.

*Nuovo Cimento*, Series 10, v. 5, no. 6, pp. 1766-1768, June 1957

A reply to Buckingham (see Abstract 54); it is claimed that Bardeen's results remain true if the gauge is chosen to give divergence  $A = 0$ . The effect of collective modes in the electron system is briefly discussed. (PA, v. 60, #8639)

**28. RELATION BETWEEN LATTICE VIBRATION AND LONDON THEORIES OF SUPERCONDUCTIVITY**

Bardeen, J.

*Physical Review*, v. 81, pp. 829-834, March 1, 1951

A gas of non-interacting electrons of small effective mass,  $m_{eff}$ , has a large diamagnetic susceptibility. It is shown that the London phenomenological equations of so small that the Landau-Peierls' theory yields a superconductivity follow as a limiting case when  $m_{eff}$  is so small that the Landau-Peierls' theory yields a susceptibility  $< -\frac{1}{4}\pi$ . Justification is given for the use of an effective mass,  $m_s \sim 10^{-4}m$ , for superconducting electrons in the lattice-vibration theory of superconductivity. This value is sufficiently small to show that the theory gives the London equations and, as a consequence, the

typical superconducting properties. The concentration of superconducting electrons,  $n_s$ , is smaller than the total electron concentration,  $n$ , by about the same ratio as the effective masses, so that  $m_s/n_s \sim m/n$ , and thus the penetration depth is of the same order as that given by the usual London expression. (PA, v. 54, #4396)

## 29. THEORY OF THE MEISSNER EFFECT IN SUPERCONDUCTORS

Bardeen, J.

*Physical Review*, v. 97, pp. 1724-1725, 1955

Mathematical. It is assumed that in the superconducting state a finite energy  $\epsilon \sim kT_c$  is required to excite electrons from the surface of the Fermi sea, and that electrons so excited behave much like excited electrons in the normal state. (CA, v. 49, 8643g)

## 30. THEORY OF BOUNDARY EFFECTS OF SUPERCONDUCTORS

Bardeen, J.

*Physical Review*, v. 94, pp. 554-563, May 1, 1954

An extension of the phenomenological London equations to take into account a space variation of the concentration of superconducting electrons is presented. The theory differs from that of Ginsberg and Landau in that it makes use of the Gorter-Casimir two-fluid model rather than an order parameter to derive an expression for the free energy. An effective wave function is used for the superconducting electrons. The theory is applied to calculate the boundary energy between normal and superconducting phases and the relative change  $\Delta\lambda/\lambda$  of penetration depth with magnetic field. Calculated values of boundary energies are somewhat larger, and  $\Delta\lambda/\lambda$  somewhat smaller, than observed. It is suggested that additional nonlinear terms are required to account for the observed  $\Delta\lambda/\lambda$  at low temperatures. The connection of the theory with Pippard's ideas on range of order is discussed briefly. (PA, v. 57, #7449)

## 31. WAVE FUNCTIONS FOR SUPERCONDUCTING ELECTRONS

Bardeen, J.

*Physical Review*, v. 80, pp. 567-574, November 15, 1950

The observed variation of the transition temperature of Hg with isotopic mass is evidence that the superconducting state arises from interaction of electrons with lattice

vibrations. The interaction term which gives scattering of electrons at high temperatures contributes at low temperatures a term to the energy of the system of electrons plus normal modes. Fröhlich has calculated the interaction energy at  $T = 0^\circ\text{K}$  by 2nd-order perturbation theory. The energy is calculated here by taking wave functions of superconducting electrons, which have energies near the Fermi surface, as linear combinations of Bloch functions whose coefficients are functions of coordinates of the normal modes. In an equivalent approximation, Fröhlich's expression for the interaction energy is obtained. When the energy is calculated directly rather than by perturbation theory, modified expressions are obtained for the energy and distribution of electrons in the superconducting state. The criterion for superconductivity is  $\hbar/\tau > \sim 2\pi kT$ , where  $\tau$  is the relaxation time for electrons at some high temperature  $T$  where  $\tau T$  is constant. It is shown that superconducting electrons have small effective mass. (PA, v. 54, #1846)

## 32. THEORY OF SUPERCONDUCTIVITY

Bardeen, J.

*Physica*, v. 24, pp. S27-S34, 1958

A review of the basis of the Bardeen-Cooper-Schrieffer theory is presented. Some of the subsequent theoretical developments, such as quasi-particle excitations are discussed. Theory and experiment are compared for the Meissner effect and thermal conductivity. (CA, v. 53, 9819i)

## 33. ZERO-POINT VIBRATIONS AND SUPERCONDUCTIVITY

Bardeen, J.

*Letter in Physical Review*, v. 79, pp. 167-168, July 1, 1950

A theory of superconductivity based on the idea that the vibrational modes of the superconducting state differ from those of the normal state in that the vibrations are such as to lower the energy of electrons in states near the surface of the Fermi distribution. The theory explains the isotope effect. (PA, v. 53, #8751)

## 34. THEORY OF SUPERCONDUCTIVITY

Bardeen, J., Cooper, L. N., Schrieffer, J. R.

*Physical Review*, v. 108, no. 5, pp. 1175-1204, December 1, 1957

A theory of superconductivity is presented, based on the fact that the interaction between electrons resulting

from virtual exchange phonons is attractive when the energy difference between the electrons states involved is less than the phonon energy,  $\hbar\omega$ . It is favorable to form a superconducting phase when this attractive interaction dominates the repulsive screened Coulomb interaction. The normal phase is described by the Bloch individual-particle model. The ground state of a superconductor, formed from a linear combination of normal state configurations in which electrons are virtually excited in pairs of opposite spin and momentum, is lower in energy than the normal state by amount proportional to an average  $(\hbar\omega)^2$ , consistent with the isotope effect. A mutually orthogonal set of excited states in one-to-one correspondence with those of the normal phase is obtained by specifying occupation of certain Bloch states and by using the rest to form a linear combination of virtual pair configurations. The theory yields a second-order phase transition and a Meissner effect in the form suggested by Pippard. Calculated values of specific heats and penetration depths and their temperature variation are in good agreement with experiment. There is an energy gap for individual-particle excitations which decrease from about  $3.5kT_c$  at  $T = 0^\circ\text{K}$  to zero at  $T_c$ . Tables of matrix elements of single-particle operators between the excited-state superconducting wave-functions, useful for perturbation expansions and calculations of transition probabilities, are given. (PA, v. 61, #1708)

### 35. MICROSCOPIC THEORY OF SUPERCONDUCTIVITY

Bardeen, J., Cooper, L. N., Schrieffer, J. R.  
*Physical Review*, v. 106, no. 1, pp. 162-163,  
 April 1, 1957

In the earlier theories of Fröhlich, Bardeen and Pines, it was supposed that superconductivity was due to a lowering of the self-energy of the individual electrons through electron-phonon interactions; a difficulty was that the calculated lowering in energy was far too large. It is now supposed that this self-energy is present in the normal state also, and that superconductivity is due to a further lowering in the total energy of the assembly through electron-electron interactions via the phonons. For small enough energy difference between the initial Bloch states, this negative interaction energy outweighs the positive Coulomb interaction, and this leads to a criterion for superconductivity almost identical with Fröhlich's. An attempt is made to estimate the form of the ground-state and its resultant energy by picking out the matrix elements most effective in lowering the energy;

these correspond to interactions between pairs of electrons of opposite spin and equal and opposite wave-vector. The energy lowering is not evaluated explicitly, but is not incompatible with the experimentally observed energy differences between normal and superconducting states. It is shown that the model explains the isotope effect and that it leads to an energy gap  $kT_g$  between the ground state and excited states; for tin  $T_g$  is estimated to be  $13.8^\circ\text{K}$ , compared with the observed  $11.2^\circ\text{K}$ . (PA, v. 60, #6193)

### 36. THE ELECTRODYNAMIC POTENTIAL IN THE GENERALIZED PHENOMENOLOGICAL THEORY OF SUPERCONDUCTIVITY

Beck, F.

*Zeitschrift für Physik*, v. 129, no. 3, pp. 246-274, 1951  
 (in German)

By introducing into the generalized non-linear theory von Laue's electrodynamic potential, it is possible to give the uniqueness proof for the stationary field. The expression for the potential also gives the force density and the angular momentum of the generalized theory. (PA, v. 54, #6978)

### 37. THE ENERGY-MOMENTUM TENSOR IN THE PHENOMENOLOGICAL THEORY OF SUPERCONDUCTIVITY

Beck, F.

*Zeitschrift für Physik*, v. 134, no. 3, pp. 334-345, 1953  
 (in German)

The unsymmetrical energy-momentum tensor introduced by Schubert, which was based on the scalar, linear theory, is not the only possible one and leads to consequences in some respects implausible. In the present paper it is shown how the equations of superconductivity and the resulting energy-momentum tensor can be formulated in a non-linear, Lorentz-invariant form. The relation between the current density  $\mathbf{J}$  and the momentum vector  $\mathbf{G} = \Lambda \mathbf{J}$  is left open. The London equation  $-c \text{curl } \mathbf{G} = \mathbf{H}$  remains unchanged, but  $\partial \mathbf{G} / \partial t = \mathbf{E}$  becomes  $\partial \mathbf{G} / \partial t + c^2 \text{grad } X = \mathbf{E}$ ,  $X = mc/e \sqrt{(c^2 - v^2)}$ , where  $v$  is the velocity of the electrons. Thus, the additional term is relativistically small. The resulting energy-momentum tensor, however, becomes symmetrical, at least in the scalar theory. In the non-scalar theory (where  $\Lambda$  is a tensor) it remains unsymmetrical, but this is justified because in this particular case angular momenta can, in fact, be exerted on the body. (PA, v. 56, #6059)

**38. ON THE PHASE TRANSITION BETWEEN SUPER- AND NORMAL CONDUCTOR IN THE CRITICAL MAGNETIC FIELD**

Beck, F.

*Annalen der Physik*, Leipzig, v. 10, no. 6-7, pp. 317-326, 1952 (in German)

The equations of the London theory are solved for a slow continuous translation of the boundary between superconductor and normal conductor for the case of an infinite superconducting semi-space. The result justifies the derivation of the critical field strength from the conservation of energy by H. London. (PA, v. 55, #8873)

**39. ON THE PHENOMENOLOGICAL THEORY OF SUPERCONDUCTIVITY (REMARKS ON A PAPER OF THE SAME TITLE BY H. KOPPE)**

Beck, F.

Note in *Zeitschrift für Naturforschung*, v. 7a, pp. 820-821, December 1952 (in German)

Attention is drawn to an error (Abstract 117), and a new relation between the superconductivity constant  $\Lambda$  and the current density is derived. (PA, v. 56, #3314)

**40. STABILITY OF A PHASE BOUNDARY INSIDE A SUPERCONDUCTOR**

Beck, F.

*Physical Review*, v. 96, no. 4, pp. 852-856, May 15, 1955

According to the London-von Laue theory a phase boundary between superconducting and normal-conducting phases inside a superconductor can exist in a stationary state in the presence of a critical magnetic field. It is shown explicitly that such a boundary is not in stable equilibrium against variations which lead to a periodic perturbation of the shape of this boundary. In connection with Pippard's idea of a finite transition region the discussion gives an outline of the meaning of this instability for the breakdown of superconductivity in the critical field. (PA, v. 58, #6156)

**41. A FEW REMARKS ON THE TWO-FLUID MODEL FOR SUPERCONDUCTORS**

Bender, P. L., Gorter, C. J.

*Physica*, v. 18, pp. 597-604, August-September 1952

The Heisenberg-Koppe version of the two-fluid model

for superconductors is compared with the original suggestion of Gorter and Casimir. The differences between the two versions are notable only at relatively low temperatures. The available data give a few indications in favor of the Heisenberg-Koppe version. (PA, v. 56, #2465)

**42. THEORY OF THE SPECIFIC HEAT OF SUPERCONDUCTORS BASED ON AN ENERGY-GAP MODEL**

Bernardes, N.

*Physical Review*, v. 107, pp. 354-357, 1957

A 2-fluid model based on forbiddenness of 1-electron states within a range of the order of  $kT_c$  from the Fermi level, with 2nd-order transition assured by energy-gap decrease vs. temp. to vanishing at transition temp., gives exponentially temp.-dependent electronic sp. heats in accord with expt. for Sn and V. (CA, v. 52, 2551 c, d)

**43. THEORY OF THE SPECIFIC HEAT OF SUPERCONDUCTORS BASED ON AN ENERGY-GAP MODEL**

Bernardes, N.

*Physical Review*, v. 107, no. 2, pp. 354-357, July 15, 1957

A two-fluid model of a superconductor is proposed, based on an approximation in which one-electron states within a range of the order of  $kT_c$  from the Fermi level are forbidden. It is assumed that the corresponding energy gap decreases with temperature and vanishes at the transition temperature; such an assumption is necessary in order to have a second-order transition. Assumptions are also made concerning the behavior of the electrons in a superconductor, and general formulae are developed involving two parameters which describe the approximate shape of the gap. Detailed calculations are presented for two different sets of values of these parameters and the results for the electronic specific heat predict the general exponential dependence on temperature which agrees with recent experimental data for Sn and V. (PA, v. 60, #7927)

**44. ON THE PRINCIPLE OF COMPENSATION AND METHOD OF THE SELF-CONSISTENT FIELD**  
Bogoliubov (Bogolubov) 1959

*Joint Institute for Nuclear Research, Dubna, USSR, Laboratory of Theoretical Physics*

The principle of compensation of the "dangerous"

graphs in the general spatially inhomogeneous case is considered. It is shown that the equations of the first approximation coincide with those of the generalized method of the self-consistent field. The obtained results are used for investigation of collective oscillations, the problem of the gauge invariance, and the Meissner effect in the theory of superconductivity. (NSA, v. 13, #11403)

#### 45. NEW METHOD IN THE THEORY OF SUPERCONDUCTIVITY

Bogolubov, N. N., Tolmachov, V. V., Shirkov, D. V.  
*Joint Institute for Nuclear Research, Moscow, and  
Akademii Nauk (SSSR) Institut Matematiki im V.A.  
Stelkov, June 1958*

The method of canonical transformations is generalized to Fermi systems and forms the basis of a method for investigating the problem of superconductivity. Starting from Fröhlich's Hamiltonian, the energy of the superconducting ground state and the one-Fermion and collective excitations corresponding to this state are obtained. It turns out that the final formulas for the ground state and one-Fermion excitations recently obtained by Bardeen, Cooper, and Schrieffer are correct in the first approximation. The physical picture appears to be closer to the one proposed by Schafroth, Butler, and Blatt. The effect on superconductivity of the Coulomb interaction between the electrons is analyzed in detail. A criterion for the superfluidity of a Fermi system with a four-line vertex Hamiltonian is established. (NSA, v. 13, #390)

#### 46. NEW METHOD IN THE THEORY OF SUPERCONDUCTIVITY

Bogolyubov, N. N., Tolmachev, V. V., Tyablikov, S. V.  
*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki, v.  
34, pp. 58-79, 1958*

I. The canonical transformation method is generalized and applied, along with the principle of compensation of "dangerous" diagrams to show that a superconducting state is inherent in the model.

II. The equivalence of the Bardeen, et al., and Fröhlich (*Proceedings of the Royal Society of London, Series A, 215, p. 291, 1952*) Hamiltonians was established in an adiabatic approximation. The energy of the ground state

and elementary excitations were calculated by the method of canonical transformations.

III. The Bardeen Hamiltonian was analyzed and a method for the summation of the principal diagrams was used. It gave the same results as those obtained above. (CA, v. 52, 15259e)

#### 47. APPLICATION OF COLLECTIVE TREATMENT OF ELECTRON AND ION VIBRATIONS TO THEORIES OF CONDUCTIVITY AND SUPERCONDUCTIVITY

Bohm, D., Staver, T.  
*Physical Review, v. 84, pp. 836-837, 1951*

The interaction between electrons and lattice vibrations suggested by Fröhlich and by Bardeen as a cause of supercond. can be treated advantageously by means of a collective description, which was originally introduced in connection with the theory of plasma oscillations. (CA, v. 46, 2867f)

#### 48. NOTE ON A THEOREM OF BLOCH CONCERNING POSSIBLE CAUSES OF SUPERCONDUCTIVITY

Bohm, D.  
*Physical Review, v. 75, pp. 502-504, February 1, 1949*

Bloch's theorem shows that even when interelectronic interactions are taken into account, the state of lowest electronic free energy corresponds to a zero net current. This result contradicts the hypothesis that superconductivity is caused by spontaneous currents. (PA, v. 52, #2516)

#### 49. ON THE THEORY OF SUPERCONDUCTIVITY

Born, M., Cheng, K. C.  
*Journal de physique et le radium, v. 9, pp. 249-252,  
October 1948*

An outline is given of a theory of superconductivity in which the interaction of electrons and metallic ions is taken into account, and according to which (in agreement with existing data) superconductivity should occur only in those metals for which the Fermi surface is close to the corners of a Brillouin zone. The transition temperature and critical magnetic fields predicted are of the right order of magnitude. (PA, v. 52, #4792)

**50. THEORY OF SUPERCONDUCTIVITY**

Born, M., Cheng, K. C.

Letter in *Nature*, v. 161, pp. 968-969, June 19, 1948

Heisenberg's recent theory is criticized, and the point of view is now adopted that superconductivity is correlated with lattice structure and is not merely a consequence of the quantum theory of interaction among electrons. An empirical rule established is that those metals are superconductive for which the Fermi surface, supposed a sphere, lies very close to one set of corners formed by the boundary planes of a Brillouin zone. An expression giving the correct order of magnitude of the transition temperature is obtained. (PA, v. 51, #3343)

**51. THEORY OF SUPERCONDUCTIVITY**

Born, M., Cheng, K. C.

Letter in *Nature*, v. 161, pp. 1017-1018, June 26, 1948

In the previous letter (Abstract 50) it was shown that in certain metals the lowest energy state corresponds to a distribution with spontaneous currents. It is now shown that these currents arrange themselves in a magnetic field in such a way that, for weak fields, London's equations between current and field hold, while for strong fields deviations are to be expected. An expression for the threshold magnetic field is obtained. (PA, v. 51, #3344)

**52. THE INTERACTIONS OF WAVES AND ELECTRONS AND REMARKS ON SUPERCONDUCTIVITY**

Brillouin, L.

*Journal de physique et le radium*, v. 18, pp. 331-336, May 1957 (in French)

(NSA, v. 11, #9350)

**53. NOTE ON THE GYROMAGNETISM OF SUPERCONDUCTORS AND DIAMAGNETIC MEDIA**

Broer, L. J. F.

*Physica*, v. 13, pp. 473-478, September 1947

It is shown that the existence both of the penetration depth and the gyromagnetic effect in superconductors can be deduced from the conservation of angular momen-

tum. The latter effect therefore can give no new information on the nature of the superconductive state. The implications of the conservation law for diamagnetic bodies are discussed briefly. (PA, v. 51, #680)

**54. A NOTE ON THE ENERGY-GAP MODEL OF SUPERCONDUCTIVITY**

Buckingham, M. J.

*Nuovo Cimento*, Series 10, v. 5, no. 6, pp. 1763-1765, June 1957

Bardeen has shown that a Meissner effect will exist if the energy spectrum of a superconductor contains a gap, if it is assumed that the matrix elements for optical transitions are unchanged by the presence of the gap. It is now shown by means of a general theorem that this assumption cannot be valid. (PA, v. 60, #8638)

**55. EQUATION OF THE MAGNETIC THRESHOLD CURVE OF A SUPERCONDUCTOR**

Burns, G. P.

Letter in *Physical Review*, v. 76, pp. 999-1000, October 1, 1949

The well-known thermodynamic result that a metal which has a  $T^3$  electronic specific heat in the superconducting state must have a parabolic  $H_c$ - $T$  curve is derived. (See also PA, #444, 1935). (PA, v. 53, #979)

**56. THEORY OF SUPERCONDUCTIVITY**

Cheng, K. C.

Letter in *Nature*, v. 163, p. 247, February 12, 1949

The criterion by Born and Cheng that metals become superconductive if a set of corners of a Brillouin zone is lying very near the Fermi surface affords an explanation of the fact that superconducting elements lie exclusively in two columns of the Periodic Table. (PA, v. 52, #5436)

**57. DO ALL METALS BECOME SUPERCONDUCTING?**

Clusius, K.

*Zeitschrift für Naturforschung*, v. 8a, p. 214, February-March, 1953 (in German)

It is suggested that superconductivity and ferromagnetism are mutually exclusive as the former shown  $B = 0$  in the interior while for the latter an internal magnetic field is characteristic. (PA, v. 56, #6061)

# 58. SUPERCONDUCTIVITY AND THE BOHR MAGNETON

Condon, E. U.

*Proceedings of the National Academy of Sciences*, Washington, D. C., v. 35, pp. 488-490, August 1949

It is pointed out that the maximum magnetization of a superconductor is  $K$  times less than a magnetization of one Bohr magneton per atom, where  $K$  is a number of order 10 and frequently close to an integral multiple of 5. The dimensional relation implied is the same as one proposed by London (PA, #226, 1946). (PA, v. 53, #1768)

# 59. MAGNETIC ENERGY AND ELECTRON INERTIA IN A SUPERCONDUCTING SPHERE

Cullwick, E. G.

*Proceedings of the Institute of Electrical Engineers*, Monograph, no. 184, June 1956

The hypothesis that the magnetic energy of a current circuit is the kinetic energy of the effective conduction electrons, developed in a previous Monograph (PA, #1397, 1956), is applied to the case of a conducting sphere without resistivity in a uniform magnetic field. A surface current is induced which prevents the growth of a magnetic field within the sphere, and expressions are found for the number and velocity of effective conduction electrons which carry the current. It is found that these electrons are in stable radial equilibrium, moving in circular orbits under the action of magnetic forces. The well-known Meissner effect in pure superconductors is shown to be an expected rather than an unexpected phenomenon, since its absence would require, under certain conditions, a supercurrent lacking equilibrium. The theory is shown to lead, by means of a simple assumption, to the basic equations of the London theory of superconductivity, but with a different interpretation of the velocity parameter. Finally, the inertial supercurrent and magnetic field which should be produced by the steady rotation of a superconducting sphere, as deduced by the new theory, are shown to be exactly the same as those forecast by the London theory. (PA, v. 59, #5108)

# 60. ON TEMPERATURE DEPENDENCE OF PENETRATION DEPTH IN SUPERCONDUCTORS

DeLaunay, J., Steele, M. C.

*Physical Review*, v. 73, pp. 1450-1454, June 15, 1948

By use of the Gorter-Casimir thermodynamic theory of superconductivity, the form of the Sommerfeld relation

for the specific heat of electrons, and of the acceleration theory expression for penetration depth, the relative number of superconduction electrons and the relative penetration depth are derived as functions of the temperature. When the parabola relationship for threshold magnetic fields is used, comparison with experiment shows good agreement. In the limit of the absolute zero temperature, it is concluded that all of the normal conduction electrons become superconduction electrons in the absence of applied magnetic fields. The parabola relationship for threshold magnetic fields is discussed. (PA, v. 51, #2838)

# 61. THE SUPERCONDUCTING TORUS

Dolecek, R. L., de Launay, J.

Letter in *Physical Review*, v. 76, pp. 445-446, August 1, 1949

The magnetic behavior of a superconducting torus is discussed theoretically. (PA, v. 53, #283)

# 62. ON THE INTERACTION OF CONDUCTION ELECTRONS WITH LATTICE VIBRATIONS

Drell, S. D.

Letter in *Physical Review*, v. 83, p. 838, August 15, 1951

Criticizes some aspects of the Bardeen-Fröhlich theory of superconductivity. The energy of the interacting electrons is calculated by means of a Block-Nordsieck type canonical transformation, rather than by perturbation or variation methods. It is concluded that these electrons do not possess a small effective mass resulting from interactions with the lattice, and that Fröhlich's shell distribution is not energetically favorable. (PA, v. 54, #8744)

# 63. SPECULATIONS ON THE BEHAVIOR OF POSITRONS IN SUPERCONDUCTORS

Dresden, M.

Letter in *Physical Review*, v. 93, p. 1413, March 15, 1954

According to current ideas positron annihilation is preceded by the formulation of positronium, the triplet state of which has a longer life than the singlet. Those positrons that land in the triplet state commonly convert into the singlet before they annihilate. It is assumed that this conversion is retarded when a metal becomes superconductive. Unpublished experiments by Stump, Talley, and Millet, are mentioned in which positrons annihilating in

lead at liquid-helium temperatures show a complex lifetime scheme with a longer-lived component, which is absent at liquid-nitrogen temperatures. (PA, v. 57, #6628)

**64. THEORY OF THE INTERMEDIATE STATE OF A SUPERCONDUCTOR**

Dzyaloshinskii, I. E.

*Doklady Akademii Nauk, SSSR*, v. 105, pp. 244-247, 1955

(CA, v. 50, 11098c)

**65. THEORY OF THE INTERMEDIATE STATE OF A SUPERCONDUCTOR**

Dzyaloshinskii, I. C.

*Soviet Research in Physics*, pp. 9-12, 1956 (English translation)

See above abstract. (CA, v. 51, 1721g)

**66. ELECTROMAGNETIC RELAXATION IN SUPERCONDUCTORS**

Eisenstein, J.

*Physical Review*, v. 82, p. 458, May 1, 1951

The transition from normal to superconductivity of a cylinder cooled in a longitudinal magnetic field or with an axial current flowing in it is discussed on the basis of equations given by Schubert. (PA, v. 54, #5424)

**67. THE SUPERCOOLING EFFECT IN SUPERCONDUCTORS CLOSE TO THE TRANSITION TEMPERATURE**

Faber, T. E.

*Proceedings of the Royal Society of London, Series A*, v. 241, pp. 531-546, September 10, 1957

The extent to which a superconducting metal can be supercooled is usually limited by the presence of flaws, which act as centers for nucleation. Close to the transition temperature, however, the flaws are too small to be effective, and the supercooling which is then observed appears to be characteristic of the ideal metal. This ideal supercooling was accurately measured for aluminum, indium, and tin, with the object of testing the various phenomenological theories of superconductivity which have lately been proposed. None of the theories is found to be completely successful. (PA, v. 61, #620)

**68. SUPERCONDUCTING ENERGY GAP INFERENCES FROM THIN-FILM TRANSMISSION DATA**

Forrester, A. H.

*Physical Review*, v. 110, pp. 776-778, 1958

The data of Glover and Tinkham (Abstract 447), on re-analysis, show that an energy gap, if one exists, is no greater than  $4.5 kT_c$  for transmission of photons of 0.3-40  $kT_c$  energy by superconducting thin films. (CA, v. 52, 16040f)

**69. ON THE THEORY OF SUPERCONDUCTIVITY: THE ONE-DIMENSIONAL CASE**

Fröhlich, H.

*Proceedings of the Royal Society of London, Series A*, v. 223, pp. 296-305, May 6, 1954

The one-dimensional case of free electrons interacting with lattice displacements is solved by a self-consistent method. It is found that for a certain range of the interaction parameter a single sinusoidal lattice displacement is strongly excited in the lowest level of the system. Its wavelength is such as to create an energy gap in the single-electron energy spectrum with all its states below filled, and all above empty. This periodic lattice displacement plays the role of an "inner field" and leads to periodic fluctuation in the electronic density in such a way that the two stabilize each other. In an infinite medium described by a periodic boundary condition they are not fixed absolutely in space, but only relative to each other. Excitation of electrons across the gap leads to a decrease in both the electronic density fluctuations and the width of the gap. The whole system, electrons plus lattice displacements, can move through the lattice without being disturbed, providing the velocity,  $v$ , is sufficiently small. The inertia of this system is equal to that of all electrons augmented by a term due to the lattice displacements. Elastic scatterings of individual electrons which normally leads to the residual resistance is impossible if  $v$  is sufficiently small. The linear specific heat of normal electrons is eliminated and replaced by an exponential term. (PA, v. 57, #6627)

**70. SUPERCONDUCTIVITY AND LATTICE VIBRATIONS**

Fröhlich, H.

*Physica*, v. 19, pp. 755-764, September 1953

A brief discussion of the theory of interaction between

electrons and lattice vibrations as the cause of superconductivity. It is pointed out that the present methods of calculating this interaction are inadequate and a possible new approach is indicated, (PA, v. 57, #3503)

**71. THEORETICAL ASPECTS OF SUPERCONDUCTIVITY. CRYSTAL STRUCTURE AND SUPERCONDUCTIVITY**

Fröhlich, H.

*Nature*, v. 168, p. 280, August 18, 1951

An optimum for the attainment of superconductivity is reached if the number of free electrons per atom is equal to  $\frac{1}{4}$ . This requires either nearly empty or nearly full Brillouin zones, which is actually the case for most superconductors. (PA, v. 54, #9492)

**72. THEORETICAL ASPECTS OF SUPERCONDUCTIVITY. SUPERCONDUCTIVITY AND EFFECTIVE MASS OF ELECTRONS**

Fröhlich, H.

*Nature*, v. 168, pp. 281-281, August 13, 1951

A criticism of Bardeen's suggestion that a very small effective mass for electrons might alone lead to superconductivity. Unless explicit account is taken of the change of interaction between electrons and the vibrational field in the presence of a magnetic field, the normal state exists and has always the lower Gibbs free energy. (PA, v. 54, #9493)

**73. THEORY OF THE SUPERCONDUCTING STATE. I. THE GROUND STATE AT THE ABSOLUTE ZERO OF TEMPERATURE**

Fröhlich, H.

*Physical Review*, v. 79, pp. 845-856, September 1, 1950

In Bloch's theory of electronic conductivity the scattering of electrons by lattice vibrations is connected with the absorption or emission of vibrational quanta. As in field theories this gives rise to a self-energy which can be calculated by application of perturbation theory. The most interesting term as a result of the Pauli principle has the form of an interaction between electrons in momentum ( $k$ ) space. The interaction between two electrons whose energy is, roughly speaking, repulsive for equal energies but different directions of  $k$ , and attractive other-

wise. If strong enough it leads in the ground state to a distribution in momentum space different from the normal (Fermi) distribution. In this case, excited states exist in which some  $(\Delta Z)$  electrons in view of their interaction in momentum space are concentrated in a narrow region in  $k$ -space. These states are stable in the sense that it requires energy to remove one of the electrons. Their energies are higher than the ground state by a term proportional to  $(\Delta Z)^2$ . For the above-mentioned ground state (identified with the superconducting state) to be realized it is found that  $\rho n \nu^{5/3}$  ( $1/n$  = atomic volume;  $\nu$  = number of free electrons per atom) must exceed a value depending on universal constants only. If  $\nu = 1$  is assumed, all monovalent metals except Li do not satisfy the required condition, but most superconductors do. The energy difference between the normal and the superconducting state at absolute zero is about  $ms^2$  ( $s$  = velocity of sound) per electron. It has thus the correct magnitude corresponding to a temperature of a fraction of a degree absolute. (PA, v. 54, #325)

**74. THEORY OF THE SUPERCONDUCTING STATE. II. MAGNETIC PROPERTIES AT THE ABSOLUTE ZERO OF TEMPERATURE**

Fröhlich, H.

*Proceedings of the Physical Society*, London, v. 64, pp. 129-134, February 1951

See preceding abstract for Part I. The London equations are now derived in the sense conjectured by F. London. (PA, v. 54, #2704)

**75. PROBLEM OF THE EXISTENCE OF LARGE DIELECTRIC CONSTANTS IN SUPERCONDUCTORS**

Galkin, A. A., Kaganov, M. I.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 25, pp. 761-763, 1953

Theoretical. The exptl. facts can be explained without recourse to a hypothesis of large values of  $\epsilon_0$ , or that the last portion of electrons undergo transition in a bound state with energy  $kT_k$ . No new anomalous effects need be expected in the frequency region  $\sim kT_k/\hbar$ . (CA, v. 49, 4350a)

**76. THE EFFECT OF SURFACE ENERGY ON THE SUPERCONDUCTING PHASE TRANSITION**

Garfunkel, M. P.

*Physical Review*, v. 87, pp. 108-110, July 1, 1952

It is shown that a positive interphase surface energy leads to hysteresis in the superconducting-normal conducting phase transition in a magnetic field. The argument is based on the simple thermodynamic theory of the phase transition. In view of these arguments, the magnetization curves of superconductors, with various simple geometries are discussed. It is shown that either superheating or supercooling or both may occur depending on the particular geometry involved. (PA, v. 55, #7295)

#### 77. CONTRIBUTION TO THE THEORY OF SUPERCONDUCTIVITY

Geilikman, B. T.

*Doklady Akademii Nauk*, SSSR, v. 94, pp. 659-662, 1954 (in Russian)

If electrons in a superconductor are regarded as a quantum liquid carrying a charge, the approach to quantum hydrodynamics lends itself readily to a theory of superconductivity. It is only necessary to add the energy of the electromagnetic field and of the field-matter interaction to the Hamiltonian of the liquid. In the course of the deductions, quantized wave-functions are introduced which are appropriate to bosons rather than to fermions; reasons to justify this procedure are given. The zero and first approximations of the theory yield the relation between electronic momentum and magnetic field strength as established by F. and H. London. (PA, v. 57, #8307)

#### 78. CONTRIBUTION TO THE THEORY OF THE SUPERFLUIDITY OF QUANTUM LIQUIDS

Geilikman, B. T.

*Doklady Akademii Nauk*, SSSR, v. 94, no. 2, pp. 199-202, 1953 (in Russian)

The liquid is represented as a continuum with kinetic energy and a potential energy depending on the density which is to account for the interaction of molecules. In first approximation, the potential energy expresses ordinary volume elasticity. Using a method of second quantization it is shown that the lowest excitation levels correspond to Landau's phonons. Using a higher approximation to the potential energy, the interaction between the phonons should be obtained. Conditions for the validity of this approach are discussed. (PA, v. 57, #6572)

#### 79. RESULTS OF THE GENERALIZED PHENOMENOLOGICAL THEORY OF SUPERCONDUCTIVITY

Geiss, J.

*Zeitschrift für Physik*, v. 129, no. 4, pp. 449-482, 1951 (in German)

The effect of substituting for the current density  $J$  in the London equations a vector  $G$ , which is a function of  $J$ , is investigated in two limiting cases. First, it is assumed that  $G$  depends non-linearly on  $J$ , but has the same direction, and the current and field distributions in a semi-infinite solid, a plate, and a wire are investigated for the case where there is a maximum current density. Second, the consequences of a linear tensor relation between  $G$  and  $J$  are worked out for the current and field distribution in a wire. (PA, v. 54, #6228)

#### 80. BEHAVIOR OF SUPERCONDUCTING FILMS IN A MAGNETIC FIELD

Ginzburg, V. L.

*Doklady Akademii Nauk*, SSSR, v. 83, no. 3, pp. 385-388, 1952 (in Russian)

The magnetic behavior of thin superconducting films is discussed in terms of the theory of Ginzburg and Landau: it is shown that if the thickness is less than  $1.12\lambda$  ( $\lambda$  = penetration depth) the transition in a magnetic field is of the 2nd order, and the critical field is given by  $\sqrt{6} H_c \lambda / d$ , where  $H_c$  is the bulk critical field. For  $d > 1.12\lambda$  the transition is 1st order. The form of the magnetization curve is also calculated. The values of  $\lambda$  deduced by comparing the limiting formulae for critical field for thick and thin films with appropriate data by Lock and Zavaritskii are not very consistent. (PA, v. 56, #5474)

#### 81. COMMENTS ON THE MACROSCOPIC THEORY OF SUPERCONDUCTIVITY

Ginzburg, V. L.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 30, no. 3, pp. 593-595, 1956 (in Russian)

A formula for the free energy of superconductors is put forward. It is argued that its theoretical foundations are reasonably safe and that it is less cumbersome to handle mathematically than the alternative formulae which have been deduced from fundamental theory. Comparison with experiment, in particular with data for aluminum and tin, is not unfavorable. (PA, v. 59, #7433)

**82. INTRODUCTION OF ANISOTROPY INTO THE THEORY OF SUPERCONDUCTIVITY**

Ginzburg, V. L.

Letter in *Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 23, no. 2 (8), pp. 236-238, 1952 (in Russian)

The Ginzburg and Landau theory is modified to take into account possible anisotropy. (PA, v. 56, #5480)

**83. MACROSCOPIC THEORY OF SUPERCONDUCTION**

Ginzburg, V. L.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 29, pp. 748-761, 1955

Theoretical math. The fundamental equations for the macroscopic London theory of supercond. in both alternating and const. fields are discussed. Special attention is paid to the measurement of surface impedance of metals. (CA, v. 50, 11098d)

**84. MACROSCOPIC THEORY OF SUPERCONDUCTIVITY APPLICABLE AT ALL TEMPERATURES**

Ginzburg, V. L.

*Doklady Akademii Nauk, SSSR*, v. 110, pp. 358-361, 1956; *Soviet Physics "Doklady,"* v. 1, pp. 541-545 (English translation)

A modification was made of the equations derived earlier making them applicable at all temperatures. (CA, v. 52, 5136b)

**85. ON THE MACROSCOPIC THEORY OF SUPERCONDUCTIVITY**

Ginzburg, V. L.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 29, no. 6(12), pp. 748-761, 1955 (in Russian). English translation in *Soviet Physics JETP* (New York), v. 2, no. 4, pp. 589-600, July 1956

The question of the basic equations of the macroscopic theory of superconductivity in steady and alternating fields is discussed in connection with some recent researches. Particular attention is paid to clarification of the character of the conclusions which can be made on the basis of measurements of the surface impedance of metals. (PA, v. 59, #8807)

**86. ON THE SURFACE ENERGY AND THE BEHAVIOR OF SUPERCONDUCTORS OF SMALL DIMENSIONS**

Ginzburg, V. L.

*Journal of Physics, USSR*, v. 9, no. 4, pp. 305-311, 1945 (in English)

The thermodynamics of the transition from normal to superconductivity of bodies of small dimensions is discussed. It is shown that the interpretation of Appleyard et al., (PA, #4134, 1939), of their measurements of critical magnetic fields of thin Hg films is modified if the difference between the surface free energies of the normal and superconductive phases is taken into account. The temperature-dependence of the penetration depth and of this difference of surface energy is estimated from the thin film results; the results do not agree well with those of Shoenberg (PA, #1630, 1940). (PA, v. 52, #2514)

**87. ON THE THEORY OF SUPERCONDUCTIVITY**

Ginzburg, V. L.

*Nuovo Cimento, Series 10*, v. 2, no. 6, pp. 1234-1250, December 1955

Macroscopic theory of superconductivity valid for magnetic fields of arbitrary magnitude, and the behavior of superconductors in weak high frequency fields are discussed. The problem of formulating a microscopic theory of superconductivity is also considered. (PA, v. 59, #2894)

**88. ROLE OF SURFACE ENERGIES IN SUPERCONDUCTIVITY**

Ginzburg, V. L.

*Physica*, v. 24, pp. S42-S47, 1958

A review (CA, v. 53, 8821f)

**89. ON THE THEORY OF SUPERCONDUCTIVITY**

Ginzburg, V. L., Landau, L. D.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 20, no. 12, pp. 1064-1082, 1950 (in Russian)

It is pointed out that the London equations for superconductivity cannot explain a positive surface energy and lead to difficulties in the interpretation of experimental results on destruction of superconductivity by magnetic fields. An attempt is made to improve the situation by modifying the fundamental ideas of the London theory; a function  $|\psi|^2$  may be considered as the density of "super-

conducting" electrons. The free energy in a magnetic field is assumed to contain a term proportional to  $|\text{grad } \psi|^2$  with the consequence that energy contributions arise not only from the kinetic energy of the supercurrent, but also from any spatial variation of the concentration of superconducting electrons; this produces a tendency to long-range order so that, for instance, at a boundary between normal and superconducting phases there is a relatively gradual transition of  $|\psi|^2$ . The form of this transition is calculated by minimization of the free energy and, hence, the interphase surface energy is evaluated in terms of the critical field and the penetration depth, but no adjustable parameters. The calculations apply only close to  $T_c$ , where reasonable agreement with the experiment is obtained. The field variation of penetration depth is calculated and found to be very small. Next the destruction of superconductivity of thin films by magnetic fields is discussed and the results of Appleyard, et al, (*Proceedings of the Royal Society of London, Series A*, v. 172, pp. 540-558 September 15, 1939) analyzed to give estimates of the penetration depth, which are claimed to be in tolerable agreement with experiment. Finally the destruction of superconductivity in thin films by currents is discussed (Abstract 179). (PA, v. 55, #1017)

#### 90. A CORRELATION FOR THE ENERGY GAP IN SUPERCONDUCTORS

Goodman, B. B.

*Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, v. 246, no. 21, pp. 3031-3034, May 28, 1958 (in French)

The ratio of  $\epsilon_0/kT_c$  is calculated for 17 superconductors from the ratio  $\gamma H_0^2/T_c^2$ , using the B.C.S. relation between the two. It varies from 1.4 to 2.0 for different superconductors, and shows a marked correlation with  $T_c/\theta_0$ . ( $2\epsilon_0$ ,  $H_0$ ,  $\theta_0$  mean energy gap, critical field, and Debye temperature at 0°K, respectively.  $T_c$  is the transition temperature,  $\gamma$  is the electronic specific heat term). (PA, v. 61, #7029)

#### 91. ON THE POSSIBILITY OF A DYNAMIC VARIETY OF THE INTERMEDIATE SUPERCONDUCTIVE STATE

Gorter, C. J.

*Physica*, v. 23, no. 1, pp. 45-56, January 1957

It is suggested that, in contradiction to F. London's supposition, the boundaries between the normal and the

superconductive regions in the intermediate state would tend to orientate themselves not perpendicular to an electric current but parallel to it. Then these boundaries would move in the direction perpendicular to the current and to the local magnetic field and the voltage drop observed in the direction of the current would be due to induction. This picture gives a natural description of the behavior of a wire in a large transversal field, or a wire carrying a large current and of the quasi paramagnetism observed for a current-carrying wire in a longitudinal field. (PA, v. 60, #8640)

#### 92. SOME FACTS ABOUT SUPERCONDUCTIVITY

Gorter, C. J.

*Physica*, v. 19, pp. 745-754, September 1953

A brief review of the facts of superconductivity followed by discussion (Lorentz Kamerlingh Onnes Conference). (PA, v. 57, #3502)

#### 93. SUPERCONDUCTIVITY

Gorter, C. J.

*Physica*, v. 15, pp. 55-64, April 1949

A short review of the phenomenological theories of superconductivity since 1934, with particular reference to thermodynamics, thermal conductivity, and thermoelectric effects. It is stressed that the understanding of the latter still presents great difficulties. (PA, v. 53, #3163)

#### 94. CRITERION FOR SUPERCONDUCTIVITY IN METALS

Groetzinger, G., Kahn, D., Schwed, P.

*Physical Review*, v. 96, pp. 887-889, 1954

A criterion for the occurrence of supercond. based on the (av.) freedom no.  $f$  of the free electrons in the metal is proposed and applied to the 9 superconductors and 12 nonsuperconductors for which the freedom no. can be calcd. on the basis of the available information. For all the superconductors the freedom no. lies between +0.15 and -0.16 and, although it is 0.14 for one nonsuperconductor, it lies outside these limits for all the other superconductors. The quantity  $\gamma (n/n_f)f$ , where  $n_f/n$  is the no. of free electrons per atom, can be calcd. for a larger no. of elements (14 superconductors and 27 nonsuperconductors) than can  $f$ . A criterion based on this quantity is fairly successful for elements with normal Hall effect and somewhat less successful for elements with anomalous

Hall effect. A comparison of the proposed criteria with those due to Kikoin and Lasarew (CA, v. 26, 1490), Frölich (CA, v. 44, 10421a), and Bardeen (CA, v. 45, 919e) shows that criteria based on  $f$  and  $\gamma$  are more successful. (CA, v. 49, 3645i)

#### 95. THE BARLOW WHEEL OF SUPERCONDUCTING MATERIAL

Heisenberg, W., von Laue, M.

*Zeitschrift für Physik*, v. 124, no. 7-12, pp. 514-518, 1948 (in German)

On the basis of the electrodynamics of superconductors the moment of force is calculated which is exerted by an axial magnetic field upon a superconducting ellipsoid of rotation into which a current is led in at the poles and withdrawn through contacts at the equator. If these contacts, including the boundary layer, are superconducting, no force is exerted. If, however, the contact is such that the current passing the boundary layer is normal a moment does occur. This is equal to that in an ordinary conductor if all dimensions of the ellipsoid are  $\ll$  the penetration depth  $d$  of the magnetic field. If they are  $\gg d$  the moment is reduced by the factor  $(2d/R)(H'/H)$  where  $R$  is the radius of the equator and  $H'/H$  the ratio of the field strength at the equator to that at infinity. (PA, v. 52, #3994)

#### 96. THE ELECTRODYNAMIC BEHAVIOR OF SUPERCONDUCTORS

Heisenberg, W.

*Zeitschrift für Naturforschung*, v. 3a, pp. 65-76, February 1948

The electrodynamic behavior of Heisenberg's model of superconductivity is examined in detail. Calculation of the constant of superconductivity  $\lambda$  gives the correct temperature-dependence of this quantity. It is now related to the residual resistance in the normal state. The derivation of the Meissner effect is attempted on different lines, making use of the existence of spontaneous current threads. The thermal conductivity is reduced by the freezing of the electrons into the electron lattice. (PA, v. 53, #232)

#### 97. THERMODYNAMIC CONSIDERATIONS ABOUT THE PROBLEM OF SUPERCONDUCTIVITY

Heisenberg, W.

*Annalen der Physik*, Leipzig, Series 6, v. 3, pp. 289-296, 1948 (in German)

From the empirical behavior of the specific heat certain conclusions are drawn about the electronic condensation phenomenon assumed to occur in the superconducting transition. The thermoelectric effects are discussed, and the electric field calculated which must occur in the presence of a temperature gradient. The behavior of a rotating superconductor is discussed in connection with the thermodynamics of the Meissner effect. (PA, v. 53, #4994)

#### 98. THE TRANSMISSION OF ELECTROMAGNETIC FORCES IN A SUPERCONDUCTOR

Heisenberg, W.

*Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen*, no. 1, pp. 23-26, 1947 (in German)

The stress tensor in F. and H. London's electrodynamics of superconductors (PA, #1791, 1935), contains an additions term  $\sim T(J) = J_i J_k - \frac{1}{2} \delta_{ik} J_i^2$ , where the  $J$  are the components of the current density and  $\delta_{ik} = 1$  for  $i = k$  and 0 for  $i \neq k$ . These stresses are discussed in the light of the theory of superconductivity (PA #3203, 1947) and their effect on the electron lattice is calculated. At the maximum current density the resulting lattice distortion can be of the order of 25%. It is pointed out that the fact that the tensor is not of the simple form  $\delta_{ik} P$  can hardly be interpreted otherwise than that the electrons are held in a rigid state, that is to say, in a lattice. (PA, v. 53, #1767)

#### 99. A NOTE ON FRÖHLICH'S THEORY OF SUPERCONDUCTIVITY

Huang, K.

*Proceedings of the Physical Society*, London, Series A, v. 64, pp. 867-873, October 1951

It is shown that the physical mechanisms underlying the two energy terms  $E_1$  and  $E_2$  in Frölich's theory are different:  $E_1$  is largely the energy change due to a modification of the lattice vibration frequencies caused by the adiabatic deformation of the electrons;  $E_2$  is on the other hand a dynamical term, representing the energy change due to virtual collisions between lattice oscillations and electrons. A proof is given that certain inadmissible consequences of the theory, pointed out recently by Wentzel, derive from the term  $E_1$ ; the superconductive behavior

discussed by Fröhlich arises, however, entirely from the term  $E_2$ . Although both terms follow from the same perturbation treatment, the analysis given makes it seem likely that whatever mechanism actually inhibits  $E_1$  will leave the superconductive behavior deduced from  $E_2$  not substantially affected. (PA, v. 55, #298).

#### 100. ON HEISENBERG'S THEORY OF SUPERCONDUCTIVITY

Kun Huang

*National Peking University, Semi-Centennial Vol., Mathematical, Physical and Biological Series*, pp. 89-101, 1948

It is pointed out that the wave packets used by W. Heisenberg to form the correlation lattice in his recent theory of superconductivity (PA, #3203, 1947) are not mutually orthogonal; the method used for obtaining their density is therefore accordingly arbitrary. This, in particular, invalidates the result that the total energy of the system can always be reduced by the formation of the correlation lattice. This result is again proved in this note by following essentially the method used by Heisenberg, but using a lattice of orthogonal wave packets. The crude estimate of the transition temperature that follows from the treatment agrees in order of magnitude with that of the usual superconductor better than that given in Heisenberg's original work. The note is concluded with a brief discussion of the exchange correlation energy which shows that conclusions reached without taking into account this effect are necessarily somewhat uncertain. (PA, v. 53, #7252)

#### 101. THE MAGNETIC THRESHOLD FIELD CURVE OF A SUPERCONDUCTOR

Hudson, R. P.

Letter in *Physical Review*, v. 85, p. 382, January 15, 1952

Correction of some algebraic errors in Abstract 55. (PA, v. 55, #2719)

#### 102. A STATISTICAL MECHANICAL TREATMENT OF CONDUCTION ELECTRONS: AN ATTEMPT TO THE THEORY OF SUPERCONDUCTIVITY

Ichimura, H.

*Journal of the Physical Society of Japan*, v. 4, pp. 265-270, July-December, 1949

It is assumed that for metals for which the Brillouin

zones overlap (the Fermi surface falls into this domain) the inter-electronic interactions are most important for electrons near the Fermi surface. For these, a cooperative interaction of the Bragg-Williams type is assumed, i.e., the interaction energy per electron is assumed proportional to the number of electrons occupying special levels above the normal Fermi distribution. The nature of this energy is not discussed and the proportionality constant arbitrarily chosen. On this basis the thermodynamical potential and the specific heat are calculated and found to represent correctly the behavior of superconductors near critical temperature. (PA, v. 53, #5845)

#### 103. THE NEW ELECTROMAGNETIC GAUGE INVARIANCE AND SUPERCONDUCTIVITY

Jouvet, B.

*Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, v. 238, pp. 454-456, January 25, 1954

The gauge invariance of the theory reported in PA, v. 57, #5286 is shown to lead to the London equations of superconductivity. (PA, v. 57, #5287)

#### 104. SUPERCONDUCTIVITY

Justi, E.

*Naturwissenschaften*, v. 33, pp. 292-297, November 30, pp. 329-333, December 15, 1946 (in German)

Review of already published knowledge. (PA, v. 51, #124)

#### 105. SUPERCONDUCTIVITY AND THE (ELECTRON-) CHAIN MODEL

Kanazawa, H., Koide, S.

*Busseiron Kenkyû*, no. 84, pp. 1-9, 1955

The bound state of an electron pair is discussed theoretically. (CA, v. 49, 13758c)

#### 106. LATTICE VIBRATION AND EFFECTIVE MASS OF AN ELECTRON (IN THE THEORY OF SUPERCONDUCTIVITY)

Kanazawa, H., Koide, S., Noguchi, T.

*Busseiron Kenkyû*, no. 58, pp. 17-24, 1953

Mathematical and theoretical. (CA, v. 47, 3104h)

# 107. PROPAGATION OF A MAGNETIC FIELD INTO A SUPERCONDUCTOR

Keller, J. B.

*Physical Review*, v. 111, pp. 1497-1499, September 15, 1958

The propagation of a magnetic field into a superconducting wire of circular cross section is analyzed theoretically. Upper and lower bounds are obtained on  $t_0$ , the time required for the field to reach the axis, and on  $R(t)$ , the inner radius of the normally conducting region. The lower bound is just the approximate result obtained by Sixtus and Tonks, Pippard and Lipshitz. It was verified experimentally by Faber for applied fields less than 1.04 times the critical field. It is believed that for the larger fields the actual results should be closer to the upper bounds. (NSA, v. 13, #1509)

# 108. MODERN THEORY OF SUPERCONDUCTIVITY

Khalatnikov, I. M., Abrikosov, A. A.

*Advances in Physics*, v. 8, no. 29, pp. 45-86, 1959

A review of bibliography. (CA, v. 53, 10982i)

# 109. ON THE EMISSION OF SOUND WAVES FROM AN ELECTRON IN A METAL AND THE THEORY OF SUPERCONDUCTIVITY

Klein, O.

*Arkiv für Fysik*, v. 5, Paper 22, pp. 459-469, 1952

(Detailed calculations for abstract below.) The probability for the emission of a phonon by an electron is calculated from Bloch's theory and it is shown that the condition for superconductivity proposed in the previous paper is only fulfilled if one assumes that a small fraction of the electron density remains stationary during the lattice vibrations. (PA, v. 56, #235)

# 110. THEORY OF SUPERCONDUCTIVITY

Klein, O.

*Letter in Nature*, v. 169, pp. 578-579, April 5, 1952

It is assumed that superconductivity occurs when the indeterminacy of the energy  $\epsilon$  connected with the lifetime of an excitation is larger than the excitation energy  $\epsilon$  for small  $\epsilon$  and smaller for large  $\epsilon$ , and that for  $\epsilon_0 \simeq kT_c$  ( $T_c$  critical temperature)  $\Delta\epsilon_0 \simeq \epsilon_0$ . Calculation of  $\Delta\epsilon$  on the basis of the Bloch model gives, however, an increase of  $\Delta\epsilon$  with  $\epsilon$ . This is in accord with the objections raised by Drell against the Fröhlich-Bardeen theories, which

are also based on the Bloch approach. Assuming, however, that a small fraction of the electron density remains stationary during the vibrations, a decrease of  $\Delta\epsilon$  with  $\epsilon$  is obtained giving reasonable values for  $T_c$  and the correct mass dependence. (PA, v. 55, #5124)

# 111. ON A NEW PHENOMENOLOGICAL THEORY OF SUPERCONDUCTIVITY

Klimontovich, Y. L.

*Doklady Akademii Nauk, SSSR*, v. 104, pp. 384-386, September 21, 1955 (in Russian)

Clarification of the Hamiltonian corresponding to the equation system of Ginzburg and Landau phenomenological theory (*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 20, no. 12, 1950) and investigation of possible physical interpretation of  $\alpha$  and  $\beta$  parameters are discussed. (NSA, v. 10, #1622)

# 112. FUNDAMENTAL CONSIDERATIONS ON THE BEHAVIOR OF A SUPERCONDUCTOR IN A MAGNETIC FIELD

Koch, K. M.

*Osterrichisches Ingenieur Archiv*, v. 3, no. 4, pp. 344-356, 1946 (in German)

The superconducting state is considered as a special case of an "ordered state" in the sense of the Bragg-Williams theory. The critical magnetic field is considered as due to an increase of ordering energy with field. It is claimed that the Meissner effect can be explained as arising from a tendency to the state of maximum order. (PA, v. 53, #281)

# 113. REMARKS ON THE "NUCLEUS" THEORY OF SUPERCONDUCTIVITY

Koch, K. M.

*Acta Physica Austriaca*, v. 4, no. 2-3, pp. 309-312 (in German)

See also above abstract. (PA, v. 54, #2698)

# 114. A DIFFICULTY IN FROHLICH THEORY OF SUPERCONDUCTIVITY

Kohn, W., Vachaspati

*Letter in Physical Review*, v. 83, p. 462, July 15, 1951

The perturbation method used in Abstract 73, leads to divergencies when excited vibrational states are assumed for the zero-order approximation. (PA, v. 54, #7908)

**115. SUPERCONDUCTIVITY**

Kok, J. A.

*Physica*, v. 24, pp. 1045-1050, 1958

A 2-component theory of supercond. is discussed. At temps. below the normal transition point the superconductor is assumed to consist of 2 components. One of these is the normal metal whereas the second has a slightly larger vol.  $V + \Delta V$ . The equil. between the electrons in the 2 states may be possible via the lattice vibrations. Some speculations are made on the normal transition temp. and on the question of what metals will become superconductive. (CA, v. 53, 10983a)

**116. SOME SPECIAL SWITCHING-ON AND RELEASE PROCESSES IN SUPERCONDUCTORS**

Konig, L. A., Schubert, G. V.

*Zeitschrift für Angewandte Physik*, v. 5, no. 1, pp. 5-9, 1953 (in German)

The London equations of superconductivity are extended by a term which takes account of the inertia of the normal electrons. This has the consequence that in processes involving the release of space charges (M. von Laue, "Theory of Superconductivity," New York: Academic Press, 1952, pp. 19-20) and the sudden switching on of a magnetic field (Abstract 193) longer relaxation times are obtained. (PA, v. 56, #6060)

**117. ON THE PHENOMENOLOGICAL THEORY OF SUPERCONDUCTIVITY**

Koppe, H.

*Zeitschrift für Naturforschung*, v. 6a, pp. 284-287, June 1951 (in German)

The temperature dependence of the constant  $\Lambda$  in the London equations leads to a dependence of the entropy on the magnetic field. This makes  $\Lambda$  dependent on the current density and leads therefore to a non-linear generalization of the theory (Abstract 425). (PA, v. 54, #9489)

**118. ON THE THEORY OF INCOMPLETE SUPERCONDUCTIVITY**

Koppe, H.

*Annalen der Physik*, Leipzig, v. 6, pp. 375-380, 1949 (in German)

The behavior of the material which contains small

inclusions in the superconductive state in a normally conducting base is investigated. In this case an ohmic conductor with a conductivity highly dependent on the magnetic field is obtained. (PA, v. 53, #6505)

**119. ON THE THEORY OF SUPERCONDUCTIVITY. II. CALCULATION OF THE TRANSITION TEMPERATURE.**

Koppe, H.

*Zeitschrift für Naturforschung*, v. 3a, pp. 1-5, January 1948 (in German)

By considering the exchange energy between electrons of equal spin, it is possible to evaluate a numerical factor which has been left open so far in Heisenberg's theory of superconductivity. This makes it possible to determine the transition temperature as a function of the atomic volume and the number of valency electrons. It is shown that this formula has the character of approximation based on the free electron model. Although fairly good agreement with experiment is found for some superconductors, the theoretical formula would give a high transition temperature for the alkali metals, for which superconductivity has actually not been observed. (PA, v. 51, #3771)

**120. AN UNBRANCHED LAMINAR MODEL OF THE INTERMEDIATE STATE OF SUPERCONDUCTORS**

Kuper, C. G.

*The Philosophical Magazine*, v. 42, pp. 961-977, September 1951

The experiments of Meshkovsky and Shalnikov on the domain structure of a sphere in the intermediate state give no support to the "branching" model described by Landau. The present theory assumes an unbranched laminar structure, and does not involve any precise assumptions about the shape of superconducting regions near the surface of the specimen. Assuming only that demagnetizing coefficients for the superconducting domains can be defined, the Landau thermodynamical potential  $L = F - (HB + hB - hH)/8\pi$  is found. By minimizing this function, the spacing and size of the superconducting domains can be calculated. The magnetization curve for ellipsoidal specimens is calculated, and is in moderate agreement with experiment. (PA, v. 54, #9495)

# 121. ON THE DESTRUCTION OF SUPERCONDUCTIVITY BY LARGE CURRENTS

Kuper, C. G.

*The Philosophical Magazine*, v. 43, pp. 1264-1275, December 1952

A theoretical study is made of the restoration of resistance in superconducting wires by large currents. The experiments of Shubnikov, Alexeevsky, and Scott show a marked deviation from the theory of F. London. The present theory uses the same geometrical model of the structure as London, i.e., a string of superconducting conical domains along the axis of the wire. But it takes account of the effect on the resistance of the scattering of electrons at successive normal superconducting interfaces, when their separation is comparable to the mean free path of the electrons in the normal phase. The scale of the structure is determined by minimizing the "Magnetic Gibbs' Function." It is shown that the interfacial surface energy may be neglected. The theory is in fair agreement with the rather scanty experimental data. The only parameter of the theory is the mean free path of electrons, and the value assigned is consistent with that obtained from other phenomena. (PA, v. 56, #1645)

# 122. ON THE GROUND STATE OF SUPERCONDUCTORS

Kuper, C. G.

*Physica*, v. 24, no. 4, pp. 304-312, April 1958

In the theory of Bardeen, Cooper, and Schrieffer, it is argued that the wave-function must contain electron-pair correlations. With several simplifying assumptions in the Hamiltonian, it then becomes possible to solve an integral equation for the wave-function. In the present work, a more restricted class of trial wave-functions is used, so that fewer approximations need be introduced into the Hamiltonian. The role of the Coulomb repulsion is discussed in some detail. The results do not differ qualitatively from those of Bardeen, Cooper, and Schrieffer. (PA, v. 61, #3147)

# 123. THE THEORY OF SUPERCONDUCTIVITY

Kuper, C. G.

*Advances in Physics*, v. 8, pp. 1-44, January 1959

An up-to-date review of the Bardeen-Cooper-Schrieffer theory and subsequent work, including a discussion of the Meissner effect problem. (PA, v. 62, #4616)

# 124. LOW TEMPERATURE PHENOMENA

Lane, C. T.

*Annual Review of Nuclear Science*, v. 1, pp. 413-440, 1952

The properties of  $\text{He}^3$  and  $\text{He}^4$  between  $0^\circ\text{K}$  and  $2.19^\circ\text{K}$  are reviewed. The property of superconductivity and methods of obtaining ultra-low temperatures are reviewed. (NSA, v. 6, #5795)

# 125. A NON-LINEAR PHENOMENOLOGICAL THEORY OF SUPERCONDUCTIVITY

von Laue, M.

*Annalen der Physik*, Leipzig, v. 5, nos. 3-5, pp. 197-207, 1949 (in German)

This new form of the phenomenological theory takes over from the older theories the separation of the conduction mechanism into an ohmic and superconductive contribution. For the latter it takes over the London equations but replaces the so far linear connection between momentum and current density by a non-linear one, which is still kept in very general terms. All essential theorems of the older theory are maintained completely or e.g., in the case of the Meissner effect, in their essential character, and therefore agreement with the experimental evidence is preserved. Essential deviations can be expected with alternating fields at high amplitudes. This new form is suitable for the notion of a maximum current density to form a part of it. (PA, v. 53, #6502)

# 126. AN EXTENSION OF THE THEORY OF SUPERCONDUCTIVITY

von Laue, M.

*Naturwissenschaften*, v. 34, no. 6, p. 186, 1947 (in German)

For the application of the London's theory of superconductivity (PA, #1797, 1935) to non-cubic crystals the scalar  $\lambda$  is replaced by a symmetrical tensor so that the vector  $(\lambda\mathbf{J})$  has the components  $(\lambda\mathbf{J})_i = \sum \lambda_{ik} J_k$ . Most of the general features of the theory (persistent currents, Meissner effect, thermodynamics of phase transition into the normal state) remain practically the same, with the only difference that the exponential decay of the magnetic field and the current density is given by two exponential functions depending on the crystallographic position of the boundary. A new feature, however, is the fact that the stress tensor is no longer symmetrical inside the super-

conductor. This causes an angular momentum per unit volume  $J \times (\lambda J)$  to be exerted upon the superconducting electrons. (PA, v. 51, #3770)

**127. THE LONDON'S THEORY FOR NON-CUBIC SUPER-CONDUCTORS**

von Laue, M.

*Annalen der Physik*, Leipzig, Series 6, v. 3, pp. 31-39, 1948 (in German)

It is shown that the main features of London's theory of superconductivity are preserved if  $\lambda$  is considered as a second rank tensor rather than a scalar. (See also Ginsburg, *Journal of Physics*, SSSR, v. 8, p. 148, 1944). (PA, v. 53, #4992)

**128. CRITICAL REMARKS ON THE THEORY OF SUPERCONDUCTIVITY**

von Laue, M.

REMARKS ON THE PRECEDING PAPER ON THE "THEORY OF SUPERCONDUCTIVITY" OF MAX VON LAUE

London, F.

REMARKS ON THE THEORY OF SUPER-CONDUCTIVITY. II.

von Laue, M.

A SPECIAL FORM OF THE ELECTRODYNAMICAL POTENTIAL OF SUPERCONDUCTORS

Beck, F.

ON THE FURTHER "REMARKS ON THE THEORY OF SUPERCONDUCTIVITY" OF MAX VON LAUE

London, F.

*Annalen der Physik*, Leipzig, v. 10, no. 4-5, pp. 296-316, 1952 (in German)

This controversy concerns certain calculations of the equilibrium between superconducting and normal phases in "Macroscopic Theory of Superconducting," (F. London, "Superfluids," v. 1, New York, John Wiley and Sons, 1950). The following are the main issues: von Laue objects to the method of calculating the electrodynamic potential of a superconducting phase by substituting for the latter diamagnetic body that produces the same external field as the superconductor. An explicit proof of the legitimacy of this procedure is given in the paper by Beck. Further, von Laue objects to the method of

determining the critical magnetic field from the equality of the thermodynamical potential of the superconducting and normal state in cases (e.g., for thin films) where electrodynamics does not permit a continuous transition from one state to the other. London's argument is that in these cases thermodynamics cannot predict whether a discontinuous transition actually takes place, but that it is of interest to look for the possible absence of an absolute equilibrium (hysteresis). It is stressed by London that the present ideas on the intermediate state and superconductors of small dimensions (which are based on a linear theory of the superconductor right up to the critical field) are not the last word in this matter and he refers to the new departures by Ginsburg and Landau (Abstract 89) and Pippard (Abstract 179). (PA, v. 55, #7300)

**129. ON THE THEORETICAL SIGNIFICANCE OF THE EXPERIMENTS BY JUSTI AND ZICKNER ON SUPERCONDUCTING INDUCTIVE NETWORKS**

von Laue, M.

*Zeitschrift für Physik*, v. 118, nos. 7-8, pp. 455-460, 1941 (in German)

Calculations in connection with experiments on the basis of complete skin effect. From the fact that the experiments agree with theory it is concluded that the state of order in a superconductor is not influenced by an electric current. (PA, v. 51, #2839)

**130. SUPERCONDUCTIVITY AND CRYSTAL GLASS**

von Laue, M.

*Annalen der Physik*, Leipzig, Series 6, v. 3, pp. 40-42, 1948 (in German)

In the extension of the London's theory to non-cubic crystals (Abstract 127) it was found necessary that the tensor  $\lambda$  should be symmetrical. It is pointed out that this symmetry is consistent with the actual crystal classes of all known superconductors. (PA, v. 53, #4993)

**131. SUPERCONDUCTIVITY AND ELECTRODYNAMIC POTENTIALS**

von Laue, M.

*Zeitschrift für Physik*, v. 125, nos. 7-10, pp. 517-530, 1949 (in German)

The electrodynamic potential is generalized to embrace superconductors in magnetic fields, including persistent

currents in rings, but not currents fed into superconductors from outside. The work done by a quasi-stationary magnetic field is calculated both for the case where the bodies belonging to the field change their position and for phase transitions between superconductive and normal state. (PA, v. 53, #2466)

**132. UNEQUIVOCAL LAWS IN THE THEORY OF SUPERCONDUCTION**

von Laue, M.

*Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen*, no. 1, pp. 86-88, 1946 (in German)

Theoretical. (PA, v. 52, #1027)

**133. TWO-FLUID MODEL OF AN "ENERGY-GAP" SUPERCONDUCTOR**

Lewis, H. W.

*Physical Review*, v. 102, pp. 1508-1511, 1956

An exponential sp. heat law in a superconductor leads to a uniquely specified form of 2-fluid model. The properties of this model are derived, and are compared with the corresponding properties of the usual Gorter-Casimir model. (CA, v 50, 14345e)

**134. INTERMEDIATE STATE OF SUPERCONDUCTORS**

Lifshits, E. M., Sharvin, Y. V.

*Doklady Akademii Nauk, SSSR*, v. 79, pp. 783-786, 1951

A discussion of previous results on the layer structure of the intermediate state of superconductors (cf. Landau, *Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 7, p. 371, 1937; v. 13, p. 377 1943). By formulae developed in the previous work, the effect of  $L$ , the sample length, on the branching of the layers was determined. The ratio of  $F'$ , the free energy of the model with branched layers, to  $F$ , the free energy of the model with the unbranched layers, is proportional to  $(\Delta/L)^{1/2}$ , where  $\Delta$  is the const. of surface tension at the boundary of the  $n$ - and  $s$ - phase, and, therefore, a decrease in the ratio would require a substantial increase in the ratio  $L/\Delta$ . Thus, for any substantial dimensions of the sample, repeated branching will not take place. However, for each value of  $L$  there is a most favorable condition that may be no branching or a single, double, or repeated branching. As  $L$  increases, it

reaches a value where the unbranched state is unstable, and then branching occurs. (CA, v. 45, 9971b)

**135. KINETICS OF DESTRUCTION OF SUPERCONDUCTIVITY BY A MAGNETIC FIELD**

Lifshits, I. M.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 20, no. 9, pp. 834-841, 1950 (in Russian)

The kinetics of the transition from the superconducting to the normal state in a magnetic field exceeding the critical is discussed theoretically. Assuming that the applied field does not change too fast and does not exceed the critical value too strongly, it can be assumed that the motion of the boundary takes place without inertia and the problem can be discussed within the framework of phenomenological theory. The equations of electrodynamics and thermal conductivity are simultaneously solved and it is shown that in certain conditions the thermal effects may have an important influence on the kinetics. The speed of motion of the boundary is determined as a function of time, applied field and other relevant parameters. (See also Abstract 264.) (PA, v. 55, #1016)

**136. ON THE PROBLEM OF THE MOLECULAR THEORY OF SUPERCONDUCTIVITY**

London, F.

*Physical Review*, v. 74, pp. 562-573, September 1948

The electrodynamics and thermodynamics of the superconducting state entail quite definite consequences with regard to the stability character of the supercurrents. In contrast to a recent attempt of Heisenberg, superconductivity is characterized in the present paper not as a state of electronic lattice order in ordinary space, but rather as a kind of condensed state in momentum space which implies a long-range order of the momentum vector  $p = mv + (e/c)A$  in ordinary space as a consequence of the requirements of quantum kinematics. Indications are that it is probably the exchange interaction associated with the Coulombian field which is responsible for this condensation in momentum space. Ferromagnetism and superconductivity thus would play the role of two opposite limiting cases of the same effect depending on whether the exchange interaction, competing with the zero-point energy, promotes parallel orientation of the electronic spins or a coordination of the translational momentum in a state of vanishing total spin. (PA, v. 52, #1031)

**137. A NOTE ON TISZA'S THEORY OF SUPERCONDUCTIVITY**

Littinger, J. M.

*Physical Review*, v. 80, pp. 727-729, November 15, 1950

The equation of F. London connecting the electric field and the current in a superconductor is derived on the basis of Tisza's theory of superconductivity. (PA, v. 54, #1848)

**138. ON THE EXISTENCE OF AN ELECTRIC FIELD IN SUPERCONDUCTORS**

Makief, B.

*Acta Physica Polonica*, v. 9, no. 2-4, pp. 141-147, 1947-1948 (in English)

By a generalization of Ohm's law and its application to the electric current in superconductors, the fundamental laws of electrodynamics of superconductivity are deduced by purely formal analogy with the equations of motion of a free charge in an electromagnetic field. For stationary currents the condition  $\mathbf{E} + (\mathbf{J} \times \mathbf{H})/nec$  (where  $n$  is the number of superconductive electrons per  $\text{cm}^3$ ) asserts that there exists in superconductors an electric field acting upon the superconduction electrons but producing no Joule's heat, as its activity  $(\mathbf{J} \cdot \mathbf{E}) = 0$ . By a train of thought starting from Hamilton's principle, the electric field is found to derive from an electric polarization inside the superconductors. The appearance of an electric polarization may be traced to a spin coupling of the electrons due to the existence of exchange forces. A calculation of the number of electrons worked out for a simplified model of a superconductor leads to a fairly good agreement with experiment. (PA, v. 52, #5438)

**139. ON THE THEOREM OF RECIPROCITY IN THE STATIONARY SUPERCONDUCTING STATE**

Marziani, M.

*Atti della Accademia Nazionale dei Lincei Rendiconti*, v. 17, no. 5, pp. 229-234, November 1954 (in Italian)

It is proved that the relation  $[\mathbf{M}_1 \times \mathbf{H}_2(O_1)] = [\mathbf{M}_2 \times \mathbf{H}_1(O_1)]$  holds in the presence of a singly connected superconductor where  $\mathbf{H}_1$  and  $\mathbf{H}_2$  are the stationary magnetic fields produced by the magnetic dipoles  $\mathbf{M}_1$  and  $\mathbf{M}_2$  situated at the points  $O_1$  and  $O_2$  outside the superconductor. The theorem is applied to the screening effect of a hollow superconducting sphere. (PA, v. 58, #4678)

**140. TWO-FLUID MODELS OF SUPERCONDUCTIVITY WITH APPLICATION TO ISOTOPIC EFFECTS**

Marcus, P. M., Maxwell E.

*Physical Review*, v. 91, pp. 1035-1042, September 1, 1953

A general form of the two-fluid model of a superconductor, which includes all previous forms, is set up and the underlying assumptions examined in the light of the lattice vibration theory of superconductivity. Thermodynamic relations are derived and their consistency with the observed isotope effects indicated. Specialization to the  $\alpha$  model of Casimir and Gorter (1934) permits fitting recent precise critical field data and evaluation of the parameter  $\alpha$  characterizing different superconductors. Comparison is made with Koppe's (PA, #1558, 1948) form of the two-fluid model, which is shown not to fit all the data, and simplified and limiting forms of his equations are given. (PA, v. 57, #473)

**141. THE FREE ENERGIES AND PHASE TRANSITION OF A CYLINDRICAL SUPERCONDUCTOR**

Marcus, P. M.

*Physical Review*, v. 88, pp. 373-381, October 15, 1952

The Helmholtz and Gibbs free energies for a cylindrical superconductor of arbitrary cross-section in a uniform axial magnetic field are defined carefully in terms of magnetic moment or total flux for the body as a whole. These definitions, applicable for arbitrary electrodynamic description of the superconductor, are transformed to equivalent forms with different density functions on assuming the London equations. A general expression is obtained for change of Gibbs function when the superconducting cross-section contracts and normal phase appears, which gives directly the critical current density condition of London for the phase transition. The critical fields are defined and compared, making use of several theorems on the dependence of the boundary section. The general formulae for free energies and critical fields are illustrated for several cross sections, including an oval shape with non-uniform boundary current density. The metastability of a superconductor described by the London equations is illustrated and discussed. (PA, v. 56, #242)

**142. A GENERAL THEORY OF MEISSNER EFFECT**  
Matsubara, T.

*Progress of Theoretical Physics*, Kyoto, v. 13, no. 6, pp. 631-632, June 1959

Introducing an external magnetic field and using Anderson's technique the method of Matsubara is applied to the theory of the Meissner effect. The resulting relation between the current and the magnetic field is the same as that given by London's equation. (PA, v. 60, #410)

**143. A THEORY OF SUPERCONDUCTIVITY, I**  
Matsubara, T.

*Busseiron Kenkyu*, no. 82, pp. 1-12, 1955

(CA, v. 49, 10687g)

**144. A THEORY OF SUPERCONDUCTIVITY, II**  
Matsubara, T.

*Busseiron Kenkyu*, no. 84, pp. 88-107, 1955

(CA, v. 49, 13758a)

**145. EMPIRICAL RELATION BETWEEN SUPERCONDUCTIVITY AND THE NUMBER OF ELECTRONS PER ATOM**

Matthias, B. T.

*Physical Review*, v. 97, no. 1, pp. 74-76, January 1, 1955

The relation between the transition temperature of a superconductor and its number of valence electrons/atom has been investigated. Optimum conditions for the occurrence of superconductivity seem to exist for 5 and 7 valence electrons/atom. (PA, v. 58, #1850)

**146. SPIN EXCHANGE IN SUPERCONDUCTORS**

Matthias, B. T., Suhl, H., Corenzwit, E.

*Physical Review Letters*, v. 1, pp. 92-94, 1958

The depression of the superconduction transition temps. of La by 1 at. % Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, and Lu is correlated only with solute atom spin. Ce behaves differently as part of the 4f electrons shifts to 5d bonding at low temp. Up to 1 at. % Gd in La lowers superconducting transition temp. linearly. Above 2.5 at. % Gd in La causes ferromagnetism approx. related to Gd content. Spontaneous moment-aligning couples may form. Up to 10 at. % concn. of Gd in Y gives moderate paramagnetism while in Th ferromagnetic solns. result. Intrinsic

superconductors may yield solute-induced ferromagnetism via facile exchange over conduction electrons. ScRu<sub>2</sub>, YRu<sub>2</sub>, LaRu<sub>2</sub>, and CeRu<sub>2</sub> are superconducting Laves phase compds. with transition temps. of, resp. 1.67, 1.52, 1.63, and 4.9°K. PrRu<sub>2</sub>, NdRu<sub>2</sub>, and ErRu<sub>2</sub> are ferromagnetic with transitions at, resp., 40, 35, and 13°K. For CeRu<sub>2</sub>, from the lattice const. observed, 25% of the 4f electrons are in outer shells, reducing the magnetic moment, and raising the no. of valence electrons, and hence, the superconducting transition temp. (CA, v. 52, 16040h)

**147. SIMILARITY PROPERTIES OF THE TWO-FLUID MODEL OF SUPERCONDUCTIVITY**  
Maxwell, E.

Letter in *Physical Review*, v. 87, pp. 1126-1127, September 15, 1952

As the normal specific heat is mass-independent a single mass-dependent parameter governs the thermodynamic functions of isotopes. (PA, v. 56, #238)

**148. PARAMAGNETIC EFFECT IN SUPERCONDUCTORS. I. THEORETICAL ASPECTS**  
Meissner, H.

*Physical Review*, v. 97, no. 6, pp. 1627-1633, March 15, 1955

A theory for the paramagnetic effect is developed under the assumption that the ratio of the effective length to the effective diameter  $l/a$  of the superconducting particles in the transition region is constant. While experiment shows that the relative apparent permeability  $K_m$ , is a function of  $\gamma = \phi_0 (1 - I_g/I)$ , where  $\phi_0 = H\phi_0/H_{z0}$  is the circular and  $H_{z0}$  the longitudinal component of the field at the surface,  $I_g$  is a limiting current, and  $I$  the total current through the sample, this theory gives the permeability as a function of  $\phi_0$  only. Good agreement with the experimental range of  $K_m$ , however, is obtained when the theoretical value of  $\phi_0$  is replaced by  $\gamma$ . The experiments of Meissner, et al., on solid and hollow mercury cylinders and recent experiments of Thompson and Squire on a solid tin cylinder are discussed. A reason why the theoretical value of  $\phi_0$  has to be replaced by  $\gamma$  cannot be given at this time, although it is indicated where the present theory must be amended. (PA, v. 58, #4681)

**149. THE PASSAGE THROUGH THE CRITICAL TEMPERATURE-FIELD REGION FOR A SUPERCONDUCTOR IN A MAGNETIC FIELD**  
Meissner, W.

*Zeitschrift für Physik*, v. 148, no. 5, pp. 607-611, 1957 (in German)

Discusses in general terms the possibility that a metal in the fully superconducting state may contain some sort of domain structure, and discusses also some consequences of Näbauer's work (see Abstract 161). (PA, v. 60, #9700)

**150. SUPERCONDUCTIVITY**

Meissner, W., Schubert, G. U.

*FIAT Review of German Science, 1939-1946; Physics of Solids, Part II*, pp. 143-162, 1948

(CA, v. 43, 2062f)

**151. DISCUSSION ON PAPERS ON SUPERCONDUCTIVITY**

Mendelssohn, K.

Report of International Conference on "Low Temperatures," 1946, *Physical Society, London, Part II*, pp. 127-128, 1948

Oxford experiments confirm results by Boorse and others on the non-superconductivity of sodium-ammonium solutions. Some pre-war experiments were also mentioned in which a current was induced in a freely suspended superconducting sphere by a magnetic field; rotation of the inducing field twisted the sphere contrary to expectation. (PA, v. 52, #578)

**152. SUPERCONDUCTIVITY**

Mendelssohn, K.

Reports on *Progress in Physics*, v. 10, pp. 358-377, 1944, 1945 (Published 1946)

Reviews with many references. (CA, v. 43, 4540e)

**153. LOW TEMPERATURE PHYSICS**

Mendelssohn, K.

Reports on *Progress in Physics*, v. 12, pp. 270-290, 1948-1949

This report covers recent advances in low temperature

technique, superconductivity, and the superfluid properties of He. Over 116 references. (PA, v. 53, #1708)

**154. ELECTRON-ELECTRON INTERACTION AND SUPERCONDUCTIVITY, I.**

Mikura, Z.

*Journal of the Physical Society of Japan*, v. 12, no. 6, pp. 587-610, June 1957

It is shown that an electron gas exhibits the Meissner-Ochsenfeld effect if a special type of electron-electron interaction,  $e^2 s_1 \cdot s_2 / r$ , is assumed and if the motion of an electron is considered to obey Dirac's relativistic equation, ( $s_1$  and  $s_2$  are the spin operators belonging respectively to each interacting electron). The perturbation method of statistical mechanics, when applied to this system, leads to the London equation though the coefficient is different from the London's original one. The theory deals in principle about the feature at absolute zero temperature in the sense that the electron-phonon interaction is not taken into account. The penetration depth of the field calculated according to the present model is quantitatively in good agreement with experiment. The known type of electron-electron interaction due to Breit, does not lead to superconductivity even in the relativistic treatment. The proposed interaction is discussed in connection with some experimental facts, i.e., the existence of an impurity effect for the penetration depth and the smaller Knight shift in the superconducting than the normal state. (PA, v. 61, #5008)

**155. THE PHENOMENOLOGICAL THEORY OF SUPERCONDUCTORS**

Miller, A. R.

Letter in *Physical Review*, v. 7, pp. 1001-1002, October 1, 1949

The derivation of the equation  $\lambda c \text{ curl } \mathbf{J} + \mathbf{H} = 0$  from the Lagrangian by Cook (1940) and Sorokin seemed to dispense with the postulate that the frozen-in magnetic induction = 0 originally made by F. and H. London (1935). It is now pointed out that the use of the Lagrangian implies that for every thermodynamic state there is only one possible value of the magnetic induction. As this is the theoretical implication of the above postulate it is hardly surprising that the derivation from the Lagrangian leads to the result without further assumptions. (PA, v. 53, #1766)

# 156. ON THE CARRIERS OF ELECTRICITY AND HEAT IN SUPERCONDUCTORS

Mirkura, Z.

*Journal of the Physical Society of Japan*, v. 3, pp. 338-342, September-December 1948

On the basis of the generally accepted concepts on metallic conduction and the structure of the intermediate state it is argued that a carrier in a superconductor has a very large electric charge compared with the ordinary electron and a large mass proportional to the charge. The interference is that the electrons in a metal begin to condense (not necessarily in co-ordinate space, but rather in momentum space) into droplets as soon as superconductivity takes place in the metal and that each droplet behaves like a "giant electron." (PA, v. 53, #5844)

# 157. ON THE THEORY OF SUPERCONDUCTIVITY

Moglich, F., Rompe, R.

*Annalen der Physik*, Leipzig, v. 6, pp. 177-192, 1949 (in German)

A discussion on the basis of the theory of plasma oscillation (following abstract). The explanation of the magnetic threshold field, given in the abstract below, is withdrawn in favor of the old thermodynamic relation that transition occurs when the kinetic energy of the supercurrent equals the free energy difference between the normal and superconductive state. It is not shown, however, that current distributions other than those given by the London equations, which could give a lower kinetic energy, are impossible in the superconductive state. Instead, a proof is given that the interaction between the transversal plasma oscillators and lattice practically disappears. (PA, v. 53, #6503)

# 158. "PLASMA OSCILLATIONS" AS THE CAUSE OF SUPERCONDUCTIVITY

Moglich, F., Rompe, R.

*Annalen der Physik*, Leipzig, Series 6, v. 1, no. 1-3, pp. 27-40, 1947 (in German)

The treatment is based on the equations of infinite conductivity of Becker, Heller, and Sauter (PA, #5413, 1933), from which they claim to be able to derive the equations of F. and H. London without introducing a further assumption. A new departure is the introduction of a restoring force for charge variations based on the zero

point pressure in Sommerfeld's theory. This gives rise to a new type of longitudinal wave. The analogue of the Debye spectrum of these and the transversal waves is calculated. Since both waves have frequencies  $> 10^{15}$  sec<sup>-1</sup> they make no noticeable contribution to the thermodynamic functions of the superconductor. (PA, v. 51, #1557)

# 159. THE MAGNETIC THRESHOLD VALUE IN THE THEORY OF SUPERCONDUCTIVITY

Moglich, F., Rompe, R.

*Annalen der Physik*, Leipzig, v. 3, pp. 322-326, 1948 (in German)

The London relation between current density and vector potential is a solution to the equation of the motion of plasma only as long as the kinetic energy of the drift velocity of the electrons  $\frac{1}{2}mv^2 \ll \partial E_0/\partial n_0$ . Here  $E_0$  is the zero point energy of the electron gas and  $n_0$  the electron density. It is assumed that superconductivity breaks down when  $\frac{1}{2}mv^2 \simeq 0.01 \partial E_0/\partial n_0$ . If one assumes for  $E_0$  the value resulting from the Sommerfeld theory magnetic threshold values of  $10^4$  to  $10^5$  are obtained. The fact that these values are 10 to 100 times larger than the observed values is ascribed to the fact that the Sommerfeld theory does not take account of the lattice field. (PA, v. 53, #6504)

# 160. SUPERCONDUCTING ENERGY GAP FROM ULTRASONIC ATTENUATION MEASUREMENTS

Morse, R. W., Bohm, H. V.

*Physical Review*, v. 108, no. 4, pp. 1094-1096, November 15, 1957

The ratio  $\alpha_s/\alpha_n$  of superconducting to normal attenuation was measured as a function of temperature  $T$  for several specimens of Sn and In at frequencies (28-56 Mc/s) such that the ultrasonic wavelength was small compared with the electronic mean free path. The variation of  $\alpha_s/\alpha_n$  with  $T$  followed quite closely a form predicted by Bardeen on the basis of the Bardeen-Cooper-Schrieffer theory. It is suggested that such measurements offer a means of finding the variation of energy gap with temperature. (PA, v. 61, #1709)

**161. THEORETICAL INVESTIGATION OF THE STABILITY OF A CYLINDRICAL PHASE BOUNDARY BETWEEN SUPER AND NORMAL CONDUCTOR IN A CIRCULAR MAGNETIC FIELD. A. BEHAVIOR FOR VIRTUAL, INFINITESIMAL, SPATIALLY PERIODIC UNDULATIONS OF THE BOUNDARY SURFACE**

Näbauer, M.

*Zeitschrift für Physik*, v. 148, no. 5, pp. 612-630, 1957 (in German)

If a toroidal coil is wound over a hollow cylindrical superconductor, the cylindrical phase boundary produced by the resultant circular field is found by experiment to be stable. It is now shown that on the London-von Laue theory the circular field should be unstable if the effect of interphase surface energy is neglected. (PA, v. 60, #9701)

**162. THE FRÖHLICH THEORY (OF SUPERCONDUCTIVITY)**

Nakajima, S.

*Busseiron Kenkyu*, no. 65, pp. 116-130, 1953

Math. and theoretical. The sound velocity and elec. resistance are discussed. (CA, v. 47, 11845h)

**163. SOME REMARKS ON SUPERCONDUCTIVITY**

Neugebauer, T.

*Hungarica Acta Physica*, v. 1, no. 4, pp. 28-38, 1949 (in German)

This gives an illustration of the difference between a diamagnetic body of zero permeability and a superconductor. The argument is extended to cover the intermediate state. Finally it is shown that the Meissner-Oxenfeld effect cannot be deduced from infinite conductivity. (PA, v. 53, #4093)

**164. THE ENERGY OF THE NORMAL ELECTRONS IN A SUPERCONDUCTOR AS A FUNCTION OF TEMPERATURE AND THICKNESS OF THE SUPERCONDUCTING LAYER ON THE FERMI SURFACE**

Niessen, K. F.

*Physica*, v. 16, pp. 84-94, February 1950

To simplify calculations Heisenberg's assumption about the superconducting layer covering a part of the Fermi

surface is modified in so far that a layer is assumed of thickness  $\Delta$  (by which is meant the difference of the energies corresponding to the upper and lower surface of the layer), which layer, covering a part  $\omega$  of the Fermi surface, is entirely inaccessible to normal electrons. A formula for the energy of the normal electrons is derived which is a function of  $\omega$ ,  $T$ , and  $\Delta$ , and which for  $\Delta \gg kT$  coincides with Koppe's expression in the Heisenberg theory, but for  $\Delta \ll kT$  is identical with the value well known from Sommerfeld's theory of metals. A special case is used to express the number of superconducting electrons per  $\text{cm}^3$  at  $T = 0$  in the transition temperature and the number of normal electrons. (PA, v. 53, #4997)

**165. ON THE CONDITION DETERMINING THE TRANSITION TEMPERATURE OF A SUPERCONDUCTOR**

Niessen, K. F.

*Physica*, v. 17, pp. 33-42, January 1951

The analogy between superconductivity and ferromagnetism suggests an analogous dependence upon temperature for the part of the Fermi sphere covered by Heisenberg's superconducting layer and the relative magnetization  $I/I_0$  in ferromagnetic material below the Curie temperature,  $I_0$  being the maximum magnetization (at  $T = 0$ ). This leads to an assumption of what happens at the transition temperature. (PA, v. 54, #4395)

**166. THE PERFECT DIAMAGNETISM OF FREE ELECTRONS WITH APPLICATION TO SUPERCONDUCTIVITY**

Osborne, M. F. M.

*Letter in Physical Review*, v. 81, pp. 147-148, January 1, 1951

A report of calculations on the behavior of a completely degenerate free electron gas in a finite box, assuming (1) a uniform magnetic field, (2) a magnetic field decaying exponentially from the surface. It is claimed that in case (1) there is almost perfect diamagnetism up to a critical field and then a triple-valued transition to a non-diamagnetic state. Below the critical field, case (2) described the penetration field. (PA, v. 54, #3532)

**167. RECENT ADVANCES IN PHYSICS**

Park, D.

*American Journal of Physics*, v. 27, no. 4, pp. 234-235, April 1959

This is an elementary review covering recent experi-

mental and theoretical developments in three areas: (1) liquid helium, (2) superconductivity, and (3) properties of elementary particles. Nucleon form factors, possible excitation states, and the universal Fermi interaction are also discussed. (PA, v. 62, #4523)

**168. LANDAU DIAMAGNETISM AND MEISSNER EFFECT**

Papaetrour, A.

*The Philosophical Magazine*, v. 42, pp. 95-105, January 1951

It is shown that, if in a superconductor the distribution of the electrons in momentum space differs a little from the spherical one, an internal field of the second type will be formed inside the superconductor; the Meissner effect then follows for not too strong external fields. (PA, v. 54, #2707)

**169. A DEFINITION AND CALCULATION OF THE COEFFICIENT OF SELF-INDUCTANCE OF A SUPERCONDUCTOR**

Philbert, G.

*Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, v. 237, pp. 1403-1405, November 30, 1953 (in French)

A generalized definition is suggested on the basis of the London's equations and worked out for a cylindrical wire. (PA, v. 57, #4554)

**170. DISTRIBUTION LAW OF SUPERCURRENTS AMONG PARALLEL SUPERCONDUCTORS**

Philbert, G.

*Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, v. 237, pp. 1148-1151, November 9, 1953 (in French)

The distribution law for  $n$  superconductors in parallel is formulated, and a special case is considered. (PA, v. 57, #4553)

**171. THEORETICAL INVESTIGATION OF SOME PROPERTIES OF SUPERCONDUCTORS**

Philbert, G.

*Journal de Physique et le Radium*, Series 8, v. 7, pp. 243-248, August 1946 (in French)

The paper deals with some applications of the London equations to superconductors of small dimensions (PA,

#5172, 1935), to the branching of supercurrents in parallel conductors and to the conservation of magnetic flux in rings. (PA, v. 51, #331)

**172. GAUGE INVARIANCE IN THE THEORY OF SUPERCONDUCTIVITY**

Pines, D., Schrieffer, J. R.

*Nuovo Cimento*, v. 10, no. 3, pp. 496-504, November 1, 1958

It is shown that when due account is taken of the Coulomb interactions between electrons, a theory of superconductivity which gives a satisfactory account of the Meissner effect in the London gauge can be extended to give a satisfactory account in any other gauge. Calculations based on the Bardeen-Pines collective treatment of the electron phonon-system show that in the long wavelength region ( $k < \sim k_c \cong r_s^{-1}$  where  $r_s$  is the interelectronic spacing) only the plasmons respond to a longitudinal vector potential. Their response is such as to maintain gauge invariance. The individual electrons are surrounded with a screening cloud of virtual plasmons in such a way that they carry no longitudinal current to order  $(k^2/k_c^2)$ , and are, hence, unaffected by a longitudinal vector potential to this order. The introduction of the screening cloud is shown to correspond closely to the backflow introduced by Feynman and Cohen to guarantee longitudinal current conservation for the excitations in liquid helium. The calculations are carried out to order  $m/M$  and  $k^4/k_c^4$ , and involve the use of the random-phase approximation for terms which couple plasmons and electrons. For the wavelength of importance in the Meissner effect ( $k \ll k_c$ ), these approximations are well-justified. An explicit prescription is given for extending the Bardeen, Cooper and Schrieffer derivation of the Meissner effect to an arbitrary gauge, and their results are shown to be essentially unaltered. (PA, v. 62, #2348)

**173. THEORY OF THE MEISSNER EFFECT**

Pines, D., Schrieffer, J. R.

*Physical Review Letters*, v. 1, no. 11, pp. 407-408, December 1, 1958

The problem of a gauge-invariant treatment of the Meissner effect is discussed, and Wentzel's treatment (Abstract 217), which leads to a different penetration depth from the B.C.S. treatment, is shown to be invalid. (PA, v. 62, #3510)

**174. V. ANALYSIS OF EXPERIMENTAL RESULTS FOR SUPERCONDUCTING TIN**

Pippard, A. B.

*Proceedings of the Royal Society of London, Series A*, v. 203, pp. 195-210, 1950

The concept of a 2-parameter 2-fluid model of supercond. is developed. The part played by the resistive mechanism in modifying the surface reactance is discussed. The temp. variation of inductive skin depth at the lowest temps. represents the variation of the superconducting penetration depth. The dependence of this quantity on crystal orientation is different from what would be expected from the theory of London and London. The resistance is found to vary too slowly with frequency and with the fraction of normal electrons. The 2-fluid model as formulated here does not give a satisfactory account of the phenomena. (CA, v. 45, 4512i)

**175. THE COHERENCE CONCEPT IN SUPERCONDUCTIVITY**

Pippard, A. B.

*Physica*, v. 19, pp. 765-774, September 1953

A brief summary of the arguments leading to the coherence concept and a consequent modification of London's equations. Preliminary results by Doidge on the sharpness of the superconducting transition in pure Sn-In alloys, and by Pippard on the variation in Sn of frozen-in flux with In content are also reported. Followed by discussion (Lorentz Kamerlingh Onnes Conference). (PA, v. 57, #3504)

**176. MAGNETIC HYSTERESIS IN SUPERCONDUCTING COLLOIDS**

Pippard, A. B.

*The Philosophical Magazine*, v. 43, pp. 237-284, March 1952

The irreversible effects exhibited in the magnetization cycle of a superconducting colloid are analysed in terms of a simple model of a superconductor. Expressions are derived relating various critical field strengths to temperature and radius of the particle; there is fair agreement between experiment and theory. (PA, v. 55, #4363)

**177. THE PHASE TRANSITION IN SUPERCONDUCTORS**

Pippard, A. B.

*Physica*, v. 22, no. 2, pp. 99-102, February 1956

By analysing a simple model of a superconductor it is shown that Van der Leeden's conjecture of a double-point belonging to the class D (1,1) on the transition line is probably not correct. Instead it appears that the transition lines for positive and negative magnetic fields are continuous in all their derivatives at the transition temperature  $T_c$ , but that just below  $T_c$  the transition line has a discontinuity of curvature where a critical point marks the change from second-order to first-order transitions. The critical point should only be detectably different from  $T_c$  for very small specimens. (PA, v. 59, #2896)

**178. THE RELATION BETWEEN IMPEDANCE AND SUPERCONDUCTING PENETRATION DEPTH**

Pippard, A. B.

*Proceedings of the Royal Society of London, Series A*, v. 191, pp. 399-415, 1947

Theory of supercond is developed. A formula is derived relating the r.f. resistivity to the superconducting penetration depth and other parameters of the metal. It is shown how the penetration depth can be deduced directly from measurements of the skin reactance, and a method of measuring reactance is described, based essentially on the variation of the velocity of propagation along a transmission line due to the reactance of the conductors. The method was applied to Hg and Sn. In the former case the results are in agreement with Shoenberg's direct measurements, and confirm that the penetration depth at 0°K is of the order  $7 \times 10^{-6}$  cm. Heisenberg's theory is discussed. (CA, v. 42, 4814i)

**179. THE SURFACE ENERGIES OF SUPERCONDUCTORS**

Pippard, A. B.

*Proceedings of the Cambridge Philosophical Society*, v. 47, Part 3, pp. 617-625, 1951

Measurements of the areas of magnetization curves of superconducting colloids and films indicate that the difference between the surface energies of the normal and superconducting states at the same temperature is much smaller than has been suggested hitherto. An attempt is made to explain the high critical fields of thin films, which led to the introduction of the surface energy, but the hypothesis that a negative interphase surface energy in films favors the persistence of superconducting threads

in fields destroys superconductivity. A model is proposed of the interface between normal and superconducting phases which allows the interphase surface energy to be positive in pure macroscopic specimens but negative in alloys and thin films and at lattice defects. This enables a qualitative explanation to be given of some of the details, such as supercooling, of the phase transition in pure metals and alloys. (PA, v. 54, #7904)

#### 180. THE THEORY OF THE ANOMALOUS SKIN EFFECT IN METALS

Reuter, G. E. H., Sondheimer, E. H.

*Proceedings of the Royal Society of London, Series A*, v. 195, pp. 336-364, December 1948

The problem of metallic conduction at high frequency and low temperatures, recently discussed by Pippard, is reformulated using the general methods of the theory of metals, and exact solutions are obtained which are valid for all frequencies and temperatures. It is shown that, for large values of the free path of the conduction electrons, the electric field is propagated through the metal as a "surface wave" which differs considerably from the classical exponential solution. The temperature variation of the surface impedance in the microwave region is considered in detail. Pippard's simplified theory is shown to be qualitatively correct, and a quantitative discussion of his experimental results is given. The frequency variation of the surface impedance at low temperatures is also discussed, and it is shown that relaxation effects are negligible in the microwave region but become important in the infrared and eventually restore the validity of the classical theory. The theory predicts that, as the frequency is increased, the reflection coefficient of metals passes through a minimum in the far infrared. (PA, v. 52, #1032)

#### 181. MEISSNER EFFECT AND GAGE INVARIANCE

Rickayzen, G.

*Physical Review*, v. 111, pp. 817-821, 1958

From gage-invariant Hamiltonians, for energy-gap supercond. models, the Meissner effect can follow. For a superconductor described by Fröhlich's Hamiltonian, with abs. zero superconductance detd. as by Bogolyubov (*Nuovo Cimento*, v. 7, p. 794, 1958), extended to apply at general temps., with current calcd. in the weak-coupling limit, there is an energy gap that leads to a Meissner effect in essential agreement with Bardeen, et al. (CA, v. 53, 58e)

#### 182. THE FIELD THEORY OF SUPERCONDUCTIVITY

Salam, A.

*Progress of Theoretical Physics*, v. 9, pp. 550-554, May 1953

Fröhlich's field theory of superconductivity is rewritten in a form in which the recent (perturbation) methods of writing down matrix elements can be readily applied. (PA, v. 57, #3500)

#### 183. ON THE THEORY OF A NON-IDEAL BOSE-GAS

Sanochkin, I. V.

*Doklady Akademii Nauk*, v. 125, no. 2, pp. 308-310, April 1959

This paper derives formulas for the ground-state energy and for the spectrum of single-boson excitations. By taking into account certain Hamiltonian terms, using partial summation of the diagrams and then applying the principle of compensating "dangerous" diagrams to the resulting model Hamiltonian, it is found that there is no gap in the spectrum, and that the expression for the energy of the elementary excitation includes a certain modified interaction potential, thus making it possible for us to study singular potentials. (*Physics Express*, v. 2, no. 1, p. 2, July 1959)

#### 184. FURTHER REMARKS ON THE QUANTUM THEORY OF SUPERCONDUCTIVITY

Schachenmeier, R.

*Zeitschrift für Physik*, v. 130, pp. 243-244, no. 2, 1951 (in German)

Schachenmeier points out that the theory of Born and Cheng is essentially the same as his own. (PA, v. 55, #1021)

#### 185. ON THE QUANTUM THEORY OF SUPERCONDUCTIVITY

Schachenmeier, R.

*Zeitschrift für Physik*, v. 129, no. 1, pp. 1-26, 1951 (in German)

It is shown that only wave-packets belonging to the degenerate part of the spectrum can be used to explain superconductivity. For elements of the second group of the periodic table these wave-packets are those near the Fermi surface. The Coulomb-exchange effect gives an ordered state of the electrons of lower energy than the

unordered. According to the theory at least two valency electrons are necessary for superconductivity, so that the alkali metals are not superconductors, although they are on Heisenberg's theory. (PA, v. 54, #4397)

**186. COULOMB INTERACTION AND THE  
MEISSNER-OCHSENFELD EFFECT**

Schafroth, M. R.

*Nuovo Cimento*, v. 9, pp. 291-303, March 1952

By application of previously developed methods (Abstract 187) it is shown that the Coulomb force in a gas of free charged particles does not produce a Meissner-Ochsenfeld effect as long as the perturbation series with respect to the Coulomb interaction converges. (PA, v. 56, #2464)

**187. REMARKS ON FROHLICH'S THEORY OF  
SUPERCONDUCTIVITY**

Schafroth, M. R.

*Helvetica Physica Acta*, v. 24, pp. 645-666, no. 6, 1951 (in German)

The introduction of magnetically polarized matter into a metal permits consideration of infinitely extended superconductors. In such a model, a very simple mathematical criterion for the occurrence of superconductivity can be given. It is then shown that the interaction between the conduction electrons and the lattice vibrations in a metal, if treated by perturbation methods, can never yield the London equation for the supercurrent in a magnetic field. The discrepancy with a result obtained by Fröhlich stems from an erroneous choice of the expression for the current density. Thus, believing the basic idea of Fröhlich's theory to be true, other approximations have to be considered. A general expression for the diamagnetic susceptibility of a gas of free charged particles, valid in any statistics, is derived by a new method. (PA, v. 55, #3599)

**188. REMARKS ON THE MEISSNER EFFECT**

Schafroth, M. R.

*Physical Review*, v. 111, no. 1, pp. 72-74, July 1, 1958

It is shown that a theory of superconductivity which starts from an "effective" Hamiltonian with significantly velocity-dependent interaction between electrons does not possess well-defined magnetic properties. The Meissner effect cannot therefore be established from such a theory.

This applies in particular to the Bardeen-Cooper-Schrieffer theory. (PA, v. 61, #5927)

**189. SUPERCONDUCTIVITY OF A CHARGED  
IDEAL BOSE GAS**

Schafroth, M. R.

*Physical Review*, v. 100, no. 2, pp. 463-475, October 15, 1955

It is shown that an ideal gas of charged bosons exhibits the essential equilibrium features of a superconductor. The onset of Bose-Einstein condensation marks the transition temperature  $T_c$ . Below  $T_c$  a Meissner-Ochsenfeld effect is exhibited which is described in a very good approximation by London's equation. The singular nature of the condensed ideal Bose gas exhibits itself in a space dependence of the London constant  $\lambda$ , determined by the boundary conditions on the wave function. It is shown that the electrostatic repulsion between the bosons compensates this effect and leads to a spatially constant  $\lambda$ , independently of the boundary conditions. The critical field  $H_c(T)$  by  $H_c = \hbar c / 2ed^2$  ( $e$  being the boson charge). The  $B(H)$  law is different from the one usually assumed for actual superconductors. Corresponding changes occur in the thermodynamical relation. A comparison with superconducting metals is made. The main conclusion is that if superconductivity in metals is due to the concurrence of bosons, then the number of these bosons must be strongly temperature-dependent below  $T_c$ . (PA, v. 59, #1252)

**190. PHENOMENOLOGICAL EQUATIONS FOR  
SUPERCONDUCTORS**

Schafroth, M. R., Blatt, J. M.

*Physical Review*, v. 100, no. 4, pp. 1221-1222, November 15, 1955

The London equations entail an infinite correlation length of the momenta of the superconducting electrons. In previous papers reasons have been given for the existence of a finite correlation length related to the mean free path. A modification of the London equation is given which is compatible with this concept. It gives an adequate explanation for the increase in penetration depth observed by Pippard when the mean free path is decreased by the addition of impurities. (PA, v. 59, #3750)

# 191. PHENOMENOLOGICAL EQUATIONS FOR SUPERCONDUCTORS

Schafroth, M. R., Blatt, J. M.

*Nuovo Cimento*, Series 10, v. 4, no. 4, pp. 786-825, October 1956

The requirement of a finite correlation length excludes the conventional London equations for superconductors. Alternative equations are proposed and discussed. Some of the consequences are: (1) a magnetic field is not completely expelled from a superconductor; the field at a large depth  $x$  is proportional to  $x^{-1}$ , rather than dropping off exponentially; (2) the Pippard effect follows as a natural consequence from the equations proposed here; (3) London's correlation between the Meissner field expulsion and persistent currents in superconducting rings depends on an infinite correlation length, and thus must be abandoned; the "persistent" ring currents must be interpreted as relaxation phenomena. The explanation of the enormously long lifetime is not possible within the framework of a purely phenomenological approach, but remains one of the tasks of a future microscopic theory of superconductivity. (PA, v. 60, #3303)

# 192. STATISTICAL THEORY OF SUPERCONDUCTIVITY

Schramm, K. H.

*Annalen der Physik*, Leipzig, v. 17, no. 2-3, pp. 115-169, 1956 (in German)

Develops the statistical mechanics of a system of "three-dimensional oscillators" of energy  $E = h\nu(n_1 + n_2 + n_3 + 3/2)$ , obeying Fermi statistics, and applies it to Kronig's (1932) "electron crystal" model of a superconductor. (PA, v. 59, #4414)

# 193. COOLING AND SWITCHING-ON PROCESSES IN SUPERCONDUCTORS ACCORDING TO VON LAUE'S THEORY

Schubert, G. U.

*Annalen der Physik*, Leipzig, Series 6, v. 5, no. 3-5, pp. 213-236, 1949 (in German)

Using von Laue's form of the London's equation two problems are discussed: (1) the exclusion of the magnetic field when superconductivity is produced by lowering the temperature (the time variation of penetration depth is taken into account), and (2) the establishment of the exclusion of a magnetic field which is suddenly applied to a superconductor at constant temperature. (PA, v. 53, #4995)

# 194. THE ENERGY-MOMENTUM TENSOR IN THE LAUE-LONDON ELECTRODYNAMICS OF SUPERCONDUCTORS

Schubert, G. U.

*Annalen der Physik*, Leipzig, v. 6, pp. 163-168, 1949 (in German)

The conservation laws for energy and momentum of a superconductor at rest can be represented in a relation between Lorentz-invariant quantities. An expression for the force density is given which can be derived from the energy momentum tensor. (PA, v. 53, #6507)

# 195. THE THEORY OF THE EFFECT OF A GROOVE IN A SUPERCONDUCTOR

Schubert, G. U.

*Zeitschrift für Physik*, v. 152, no. 5, pp. 624-641, 1958 (in German)

The London equations are solved for a plane superconducting surface with a groove in it of semi-circular or semi-elliptical cross-section, running parallel to the magnetic field. (PA, v. 62, #1489)

# 196. ELECTRIC AND MAGNETIC BEHAVIOR OF NIOBIUM NITRIDE AT THE TRANSITION TO SUPERCONDUCTIVITY

Sellmeier, A.

*Zeitschrift für Physik*, v. 141, pp. 550-565, 1955

The paramagnetic effect (increase in magnetic flux in the transition region to superconductivity) in NbN was investigated. The effect was absent in samples contg. less than 49.7 at % of nitride. However, the one sample with 49.7 at % showed a flux increased by a max. of 63% over that in the normally conducting state for fields of 0.5 to 4 gauss, and currents up to 20 amp. This result agrees with those observed for pure metals. (CA, v. 50, 11743d)

# 197. ON THE COMPENSATION EQUATION IN SUPERCONDUCTIVE THEORY

Shirkov, D. V.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 36, pp. 607-612, February 1959 (in Russian)

A relation is established between the matrix elements of the variational derivatives of the scattering matrix and energy operator. With the help of this relation the kernel of the integral equation for the compensation of "dangerous" diagrams is expressed through the usual Green's functions. (NSA, v. 13, #10252)

**198. RECENT RESEARCH ON SUPERCONDUCTIVITY IN THE U.S.S.R.**

Shoenberg, D.

*Nuovo Cimento*, v. 10, Supplement no. 4, pp. 459-480, 1953

A descriptive survey with bibliography of work done since about 1946 under the following headings: The intermediate state; The effects of pressure on the superconducting transition, etc.; New superconducting compounds; Thin superconducting films; Measurements at radiofrequencies; Miscellaneous—the superconducting transition, thermodynamic properties, penetration depth measurements; Theoretical work. (PA, v. 57, #3497)

**199. SUPERCONDUCTIVITY**

Shoenberg, D.

Cambridge: University Press, 1952

Review in *Proceedings of the Physical Society*, London, Series A, v. 66, p. 775, August 1953

(PA, v. 56, #6801)

**200. THE SUPERCONDUCTING CYLINDER AND SPHERE IN A MAGNETIC FIELD**

Silin, V. P.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 21, pp. 1330-1336, no. 12, 1951 (in Russian)

The magnetic behavior of a superconducting cylinder and sphere are re-examined according to the theory of Ginsburg and Landau. For small fields the formulae for  $X/X_0$  become, in the limiting cases of "small" and "large" specimens, identical with those obtained from the London theory. For destruction of superconductivity a critical size is found in each case below which the transition becomes of the second rather than the first order. The destruction of superconductivity of thin wires by a current is also briefly discussed. (PA, v. 55, #5973)

**201. FORCES ACTING ON SUPERCONDUCTORS IN MAGNETIC FIELDS**

Simon, I.

*Journal of Applied Physics*, v. 24, pp. 19-24, January 1952

The forces acting on a superconducting body in a magnetic field may be obtained by analogy with hydrody-

namics, considering the similarity of the force field around a perfect diamagnetic with the flow field of an ideal liquid past an impermeable body of the same shape. The translation is provided by replacing  $\frac{1}{2}\rho v^2$  by  $(\frac{1}{8}\pi)\mu H^2$ . As a practical application of the repulsive forces acting on superconductors in a diverging magnetic field, design of two types of magnetic supports for a sphere is described. In the coil-type support, two coils with opposed currents are necessary to provide stable equilibrium. Similarly, the permanent-magnet-type support requires two transversely magnetized rings with opposed polarity. The dissipation of energy in a rotating sphere by eddy currents and by viscous drag of the surrounding gas was studied. The non-existence of any torque on a free-floating, superconducting sphere in a rotating, transverse field indicates absence of interaction between the superconducting electrons and the metallic lattice. (PA, v. 56, #2466)

**202. REMARKS ON THE THEORY OF SUPERCONDUCTIVITY**

Sommerfeld, A.

*Zeitschrift für Physik*, v. 188, no. 7-8, pp. 467-472, 1941 (in German)

It is shown that the relation between the magnetic threshold field at absolute zero and the critical temperature postulated by Welker from his electron theoretical model, is in agreement with one that can be deduced from the thermodynamics of superconductors of Kok and Gorter and Casimir. (PA, v. 51, #2840)

**203. SIZE EFFECTS IN THE SUPERCONDUCTIVITY OF CADMIUM**

Steele, M. C., Hein, R. A.

Letter in *Physical Review*, v. 87, p. 908, September 1, 1952

From the increase in magnetic threshold value with decreasing particle size a zero point penetration depth of  $\sim 10^{-4}$  cm is estimated. (PA, v. 56, #237)

**204. SUPERCONDUCTIVITY BELOW 1°K**

Steele, M. C.

Letter in *Physical Review*, v. 87, pp. 1137-1138, September 15, 1952

Straightforward thermomagnetic considerations explain the positive  $\partial I / \partial H$  ( $I$  magnetic moment of a superconductor,  $H$  magnetic field strength) found by Daunt and

Heer when warming up superconductors in a magnetic field. (PA, v. 56, #239)

## 205. SUPERCONDUCTIVITY OF TITANIUM

Steele, M. C., Hein, R. A.

*Physical Review*, v. 92, pp. 243-447, 1953

Crit. magnetic field of 2 specimens of Ti were measured down to 0.23°K. The first specimen was a cold-worked Ti wire, 99.98% pure. It superconducting at 0.37°K. in a zero magnetic field, and the initial slope of the crit. field curve was 465 gauss per deg. The 2nd specimen was a Ti crystal bar, > 99.99% pure. Its transition temp. was 0.49°K., and the crit. field curve was 400 gauss per deg. (CA, v. 48, 1745c)

## 206. TRANSITION PROCESSES IN A PLANE-BOUNDED PLASMA

Stratonovich, R. L.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 24, no. 3, pp. 269-278, 1953 (in Russian)

Boundary values are found, (1) the deviation from the equilibrium distribution function, (2) potential of the electric field and (3) gradient of charge density, in processes which take place in a semi-space when a given potential is applied to a plane reflecting electrode which acts as the plasma boundary. A method is described of determining transition processes in a semi-infinite plasma and in a layer between 2 electrodes maintained at a constant potential difference, using a special form of stationary function of distribution. Formulae are obtained which express the reaction of the plasma to different disturbances, in particular to the function with a rectangular well [ $H(t) = 1$  at  $t \geq 0$ ;  $H(t) = 0$  at  $t < 0$ ]. (PA, v. 57, #8309)

## 207. EXCHANGE SCATTERING IN SUPERCONDUCTORS

Suhl, H., Matthias, B. T.

*Physical Review Letters*, v. 2, pp. 5-6, January 1, 1959

The theory of superconductivity is discussed in view of previous theories and experiments. It was previously suggested that the depression of the superconducting transition temperature of lanthanum as a function of rare earth impurity content may be traced to the exchange interaction between the conduction-electron spins and  $f$ -shell spins of the rare-earth ions and conduction electrons inter-

act via the ionic spins to modify the effective "V." From present and previous works, it is concluded that the important course of the depression of  $T_c$  by exchange scattering is the disparity in the free-energy depressions of the normal and superconducting states. "Shift V" effects, whether due to changes in wave function or due to electron interactions via virtual states, are small by comparison. The exchange energy between conduction electrons and ionic spins necessary to account for the observed reductions in  $T_c$  is 0.15 volt. (NSA, v. 13, #4208)

## 208. AN ATTEMPT TO TREAT THE INTERACTION BETWEEN ELECTRONS AND LATTICE VIBRATIONS

Takano, F.

Note in *Journal of the Physical Society of Japan*, v. 9, pp. 430-431, May-June 1954

In Bardeen's theory of superconductivity interelectron correlations were neglected, and the averaging over the normal modes of the lattice was ambiguous. A more rigorous calculation indicates that the system should be treated as a whole; an equation is derived for the electronic energy-level shift due to interaction with the lattice which is similar to Bardeen's, though more complex. (PA, v. 57, #11080)

## 209. SUPERCONDUCTING ENERGY GAP INFERENCES FROM THIN-FILM TRANSMISSION DATA

Tinkham, M., Glover, R. E., III

*Physical Review*, v. 110, no. 3, pp. 778-779, May 1, 1958

A reply to Forrester (Abstract 68). The results are plotted in a new form, which shows the close agreement with the B.C.S. theory and strongly suggests the existence of an energy gap of 3-4  $kT_c$ . (PA, v. 61, #5926)

## 210. THEORY OF SUPERCONDUCTIVITY

Tisza, L.

*Physical Review*, v. 80, pp. 717-726, November 15, 1950

A quantum-mechanical model has been developed exhibiting the characteristic properties of superconductors. Localized "atomic" wave functions are used to construct many-electron wave functions obeying the exclusion principle and corresponding to definite electronic localiza-

tion ( $\phi$ -functions). The crystal translations will take these over into a set of say,  $\omega$ , equivalent  $\phi$ -functions. Quantum resonance of these provides a zero-order wave function with the correct symmetry properties ( $\psi$ -functions). The  $\phi$ -functions of small  $\omega$  have a high translational symmetry and are referred to as "electron-lattices." The model has superconducting properties if its lowest state is described by a  $\psi$ -function obtained through the resonance of at least three resonating electron lattices, and if this state is somewhat depressed below the continuum of high  $\omega$ -states. The latter can also be described in the standard band formalism. In the absence of external fields the lowest state is without a current. If the transition from  $\phi$  - to  $\psi$  - functions is carried out in the presence of a magnetic field, one automatically obtains a current "induced" by the field, and connected with it by the well-known London relation. The present method is not adequate to prove that the conditions stated are actually satisfied in superconductors. Nevertheless, qualitative quantum-chemical arguments make it appear plausible that these conditions are satisfied in the regions of the periodic table where the actual superconductors are located. Conversely, if the theory is accepted, a rather detailed insight is gained into the quantum-chemical properties of superconductors. The recent experimental and theoretical work on the isotope effect is being discussed. (PA, v. 54, #1847)

## 211. ON THE MATTER OF THE SUPERCONDUCTING STATE

Tisza, L.

Letter in *Physical Review*, v. 84, p. 163, October 1, 1951

Application of symmetry considerations to the coupling between electron and phonon gas gives a possible phase transition into a state exhibiting a superstructure as in the preceding abstract. (PA, v. 55, #299)

## 212. CONCERNING A NEW METHOD IN THE SUPERCONDUCTIVITY. II.

Tolmachev, V. V., Tyblikov, S. V.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 34, no. 1, pp. 66-72, 1958 (in Russian)

In the adiabatic approximation, equivalence of the Bardeen Hamiltonian and Fröhlich Hamiltonian is established and the energies of the ground state and elementary excitations are calculated by the method of canonical transformation. (PA, v. 61, #7035)

## 213. RECENT ADVANCES IN SCIENCE: PHYSICS

Vick, F. A.

*Science Progress*, v. 37, pp. 268-274, 1949

A review of recent researches on superconductivity especially at low temperature. (CA, v. 43, 6051d)

## 214. ON THE CONNECTION BETWEEN SUPERCONDUCTIVITY AND MIXED CONDUCTIVITY

Welker, H.

*Annalen der Physik*, Leipzig, v. 5, no. 1-2, pp. 1-13, 1949 (in German)

On the basis of theoretical considerations on the band-model and from experimental results it is shown that only conductors with overlapping electron bands can become superconductors. The magnitude of the translatory zero-point energy of the conduction electrons and positive holes gives a measure of the value of the transition temperature. (PA, v. 53, #6501)

## 215. A WAVE-MECHANICAL MODEL OF THE SUPERCONDUCTOR

Welker, H.

*Zeitschrift für Naturforschung*, v. 3a, pp. 461-469, August-November 1958 (in German)

Hypothetical wave functions are constructed for the purpose of illustrating the type of electron interaction which may lead to superconductivity. These wave functions are degenerate and magnetic interaction produces an energy gap. A qualitative explanation of superconductivity analogous to Bethe's theory of superstructure is given. It is essential for the model that the superconductor should be a mixed conductor, as defect electrons are used to build up the hypothetical wave function (another consequence of the types of densities within which superconduction is possible). This is verified by comparison with the range of atomic values occupied by the known superconductors. The maximum electron density is, however, not in agreement with the theoretical prediction. Some conclusions concerning the lattice structure of superconductors are indicated. (PA, v. 52, #1915)

## 216. THE INTERACTION OF LATTICE VIBRATIONS WITH ELECTRONS IN A METAL

Wentzel, G.

Letter in *Physical Review*, v. 83, p. 168, July 1, 1951

Using perturbation theory, Bardeen and Frölich have attributed superconductivity to strong interaction between the electrons and the lattice vibrations in the crystal, and hence, have obtained a condition for the occurrence of superconductivity. It is now pointed out that this condition and the condition for perturbation theory to be satisfactory, appear to be mutually exclusive. For an improved discussion, the one-dimensional model of Bloch and Tomonaga is available, in which phonons and electrons are supposed to propagate in the two (opposite) directions. This model is discussed and rejected since (a) it appears to lead to certain complications, which are pointed out, and (b) no analogous description appears so far to be available for the three-dimensional case. It is concluded that the strong coupling assumption is not well-founded at this time. (PA, v. 54, #7907)

#### 217. MEISSNER EFFECT

Wentzel, G.

*Physical Review*, v. 111, no. 6, pp. 1488–1492, September 1958

The magnetic properties of the Bardeen-Cooper-Schrieffer model of a superconductor are investigated by means of Bogoliubov's mathematical method. A derivation of the Meissner effect is given which is strictly gauge invariant in every step. (PA, v. 62, #1484)

#### 218. PROBLEM OF GAUGE INVARIANCE IN THE THEORY OF THE MEISSNER EFFECT

Wentzel, G.

*Physical Review Letters*, v. 2, no. 2, pp. 33–34, January 15, 1959

A reply to criticisms by Pines and Schrieffer (Abstract 173). (PA, v. 62, #3511)

#### 219. SUPERCONDUCTIVITY AND THE ELECTRON-PAIR MODEL

Weyerer, H.

*Zeitschrift für Naturforschung*, v. 13a, pp. 402–404, 1958

Theoretical. Supercond. is treated as idealized "spinons" which are bosons. Supercond. occurs when the d. of the spinons exceeds a min. value of  $\approx 1.4 \times 10^{16} T_s^{3/2}/\text{cc}$ ,

where  $T_s$  is the transition temp. The disassoc. of the spinons depends on the temp. and on the magnetic field. The variation in supercond. among elements in relation to their positions in the periodic table is discussed. (CA, v. 52, 19478g)

#### 220. ON THE THEORY OF SUPERCONDUCTORS Wisniewski, F. J.

*Comptes Rendus Hebdomadaires des Séances de l'Académie des Sciences*, v. 226, pp. 1964–1965, June 14, 1948 (in French)

From the Hamilton-Jacobi equation of an electron moving freely in a magnetic field  $H$  the relation  $\text{curl}(mv) + (e/c)H = 0$  is derived, where  $v$  is the velocity of the electron. This is identical with one of the equations of superconductors of F. and H. London, and it is concluded that superconductivity will occur if the lattice vibrations are small enough not to impede free movement of electrons. The case of a frozen-in magnetic field (which is possible for a free electron but does not occur in a superconductor) is not considered. Some thermodynamic considerations of the disturbing influence of a strong magnetic field are added. (PA, v. 52, #1029)

#### 221. REMARKS ON THE THEORY OF SUPERCONDUCTIVITY

Yoshida, K.

*Physical Review*, v. 111, pp. 1255–1256, September 1, 1958

The relation between the Bardeen-Cooper-Schrieffer theory and the Bogoliubov theory of superconductivity is discussed. It is shown that the B.C.S. trial-wave function is derived by the same transformation as that used by Bogoliubov, and that the integral equation which determines an introduced parameter is equivalent. Some remarks are also made on the excited-state functions. (NSA, v. 13, #912)

#### 222. SUPERCONDUCTIVITY

Zavaritskii, N. V.

*Priroda*, v. 45, no. 3, pp. 37–44, 1956

A short review of the phenomenon of superconductivity. (CA, v. 50, 9074)

## II. EXPERIMENTAL

### A. Meissner Effect

#### 223. EDDY CURRENTS AND SUPERCURRENTS IN ROTATING METAL SPHERES AT LIQUID HELIUM TEMPERATURES

Alers, P. B., McWhirter, J. W., Squire, C. F.

*Physical Review*, v. 84, pp. 104-107, October 1, 1951

These experiments show that large eddy currents are set up in a Sn sphere rotating at 4.6 or more rps in the Earth's magnetic field and 3.8°K. Within experimental determination, the eddy currents have the same magnitude and distribution on the sphere as the supercurrents which cause the Meissner effect at 3.7°K. These results are in accord with classical electromagnetic theory for a normal conductor and with the London theory for a superconductor. The Meissner effect has been produced in bulk Ta metal by rotating the specimen while cooling through the superconducting transition temperature. (PA, v. 54, #9485)

#### 224. PARAMETRIC EFFECT IN SUPERCONDUCTORS. IV. MEASUREMENTS ON ALUMINUM

Fitch, A. H., Meissner, H.

*Physical Review*, v. 106, no. 4, pp. 733-736, May 15, 1957

A cryostat has been designed and constructed to permit investigation of superconductors having transition temperatures in the range from 1.4°K to below 0.9°K. By means of this cryostat, the paramagnetic effect, previously observed in In, Sn, Ta, Hg, Tl and NbN, has been observed at the superconducting transition of aluminum. The threshold current,  $I_0$ , required for the occurrence of the paramagnetic effect, had previously been shown to be related to the applied longitudinal field,  $H_{z0}$ , and the specimen diameter  $d$ , by the equation  $I_0 = I_g + \gamma^* \pi H_{z0} d$ , where  $I_g$  and  $\gamma^*$  are constants characteristic of a particular superconductor. Preliminary measurements on the six superconductors listed above had suggested that  $I_g$  values occur only in multiples of 0.6 ampere. Measurements of  $I_g$  for aluminum yield an  $I_g$  value definitely less than 0.6 A. (PA, v. 60, #7124)

#### 225. ISOTOPE EFFECT ON THE SUPERCONDUCTING TRANSITION IN LEAD

Hake, R. R., Mapother, D. E., Decker, D. L.

*Physical Review*, v. 112, no. 5, pp. 1522-1532, December 1958

Observations of the difference in critical fields of superconducting Pb specimens of different isotopic mass are described. Measurements are made using the Meissner effect and a ballistic induction method in the range from 7.2 to about 1.4°K. The results near  $T_c$  verify the theoretical prediction that  $T_c = \text{const} \times M^p$ , where  $M$  is the average isotopic mass, and yield a value of  $p = 0.501 \pm 0.013$ . The measurements at lower temperatures are inconclusive in their implications for the isotope effect, since all specimens measured exhibit large deviations from the predictions of the similarity principle. The deviations are apparently not related to the isotopic mass of the specimens. The agency responsible for the observed deviations has not been isolated, but it is believed that the anomalous  $H_c$  values are characteristic of thermodynamically irreversible transitions. Thus, the present results are not believed to constitute genuine evidence of a deviation from the similarity principle. (PA, v. 62, #3508)

#### 226. THE MAGNETIC PROPERTIES OF SUPERCONDUCTING ALLOYS OF INDIUM AND THALLIUM

Love, W. F., Callen, E., Nix, F. C.

*Physical Review*, v. 87, pp. 844-847, 1952

Magnetization curves for alloys on In with 5, 10, 17, 25, 30, and 37% Tl were measured as a function of temp. and compn., and crit. field curves were obtained. These alloys show a fairly strong Meissner effect, and the breadth of the transition region increases for increasing Tl content. Alloys of high Tl content have magnetic properties strongly sensitive to mech. shock while in the intermediate state. (CA, v. 46, 10725a)

#### 227. SUPERCONDUCTIVITY IN TIN-BISMUTH AND TIN-ANTIMONY ALLOYS

Love, W. F.

*Physical Review*, v. 92, pp. 238-243, October 15, 1953

The Meissner effect in a series of spherically shaped

solid solution alloys of these metals has been investigated. Magnetization curves have been obtained as a function of temperature and composition, from which critical field curves and transition temperatures have been derived. Increasing breadth of the magnetization curves and frozen-in moment have been observed with increasing solute concentration. Thermodynamic analysis of the critical field data has shown an interesting variation of the electronic specific heat coefficient  $\gamma$  with solute concentration, which has been interpreted in terms of the overlapping band structure of tin. (PA, v. 57, #1331)

## 228. MEASUREMENTS OF SUPERCONDUCTING CONTACTS

Meissner, H.

*Physical Review*, v. 109, no. 3, pp. 686-694, February 1, 1958

The contact resistance between crossed wires was measured as a function of the current at various temperatures in the liquid-helium range. Most contacts were stable enough to establish a "diagram of state," i.e., determine curves of constant resistance in I-T space. The following facts were established: (1) The critical temperature of contacts between clean wires of tin is suppressed by about  $0.2^\circ\text{K}$  due to the pressure of the contact; (2) The addition of a copper layer on one or both of the wires reduces the critical currents, but hardly influences the critical temperature. This can be understood if one assumes that the density of the superconducting electrons decreases in the copper layer, thus producing an increase in the penetration depth. At layer thicknesses of several hundred angstroms the penetration depth becomes large compared to the contact radius, and the critical current vs temperature curve approaches that of a very thin wire; (3) Contacts between tin and copper wire below the critical temperature and at low currents show a constant resistance, which rises sharply at a critical current. Graphs of this quasi-critical current as a function of the temperature were obtained; (4) Clean contacts between tin and indium usually behave as one would expect from the foregoing. In one case out of three, however, the resistance was strongly dependent on the current at a temperature as high as  $4.2^\circ\text{K}$ . Plotting the low-current values of the resistance as a function of the temperature showed a behavior as if one of the contact materials had a critical temperature of 5 to  $6^\circ\text{K}$ . A search of the literature revealed that the Sn-In system has two intermetallic compounds. The compound  $\text{In}_3\text{Sn}_2$  was prepared, and was

found to have a critical temperature of about  $5.5^\circ\text{K}$ . Since the contacts were closed at  $4.2^\circ\text{K}$  and no possibility of transfer of metal from one side to the other existed, it must be assumed that the proximity of the tin to the indium is sufficient to produce partial superconductivity by way of long-range correlation of the electronic wavefunctions. (PA, v. 61, #8789)

## 229. MEASUREMENTS IN THE TRANSITION REGION TO SUPERCONDUCTIVITY

Meissner, W., Schmeissner, F., Meissner, H.

*Zeitschrift für Physik*, v. 130, pp. 521-528, no. 4, 1951 (in German)

There is no change in the external magnetic field produced by a current when specimens (coils and straight wires of Sn) change from the normal to the superconductive state. The observation of K. Steiner (Abstract 269) is confirmed, according to which the flux of a longitudinal magnetic field in a straight Sn specimen increases above its normal value before it is finally expelled, if the specimen carries a current  $>$  than a certain value  $J_0$ . In these experiments the temperature is changed and the change of flux measured by an induction coil connected to an oscillograph. (PA, v. 55, #1806)

## 230. MEASUREMENTS IN THE TRANSITION REGION TO SUPERCONDUCTIVITY

Meissner, W., Schmeissner, F., Meissner, H.

*Zeitschrift für Physik*, v. 130, pp. 529-538, no. 4, 1951 (in German)

Continuation of the experiments (preceding abstract) with Sn and Hg. Individual points of the transition region are investigated by measuring the change in flux when the longitudinal field  $H$  is reversed. The apparent maximum permeability  $\mu$  reaches values  $> 2$ . It is a linear function of the current  $J$ .  $(\partial\mu/\partial J)_{H,T}$  varies from specimen to specimen and with Hg it differs when it is melted and re-frozen. However, the minimum current  $J_0$  at which an increase of  $\mu$  takes place is reproducible and can be expressed by  $J_0 = J_g + \gamma Hd\pi$ , where  $d$  is the diameter of the specimen,  $J_g$  a current and  $\gamma$  a numerical factor both characteristic for the element. Including the results of Abstract 269 the values  $J_g = 0.6; 1.2; 1.7; 0.6$  amps and  $j = 0.67; 0.67; 0.37; 0.37$ ; are obtained for In, Sn, Hg, Tl respectively (see Abstract 371). (PA, v. 55, #1807)

**231. PARAMAGNETIC EFFECT IN SUPERCONDUCTORS. V. RESISTANCE TRANSITION OF TIN WIRES**

Meissner, H.

*Physical Review*, v. 109, no. 3, pp. 668-680, February 1, 1958

The resistance of tin wires between 0.15 and 3 mm in diameter was measured as a function of the current in the transition region to superconductivity. The samples used were, with one exception, single crystals and had residual-resistance ratios  $r_0 = R_0^\circ\text{K}/R_{273}^\circ\text{K}$  of a few times  $10^{-5}$ . Most of the transition curves showed a steep rise and a break at the critical current. The critical resistance, defined as the resistance at the break of the curves, is for single crystals independent of the temperature between  $1.9^\circ\text{K}$  and the critical temperature, if proper corrections for the temperature dependence and the field dependence of the resistivity are made. Extensive measurements of these dependences have been made for this purpose. Measurements on one polycrystalline sample and comparison with measurements by Rinderer showed a strong influence on the electronic mean free path on the ratio of the critical resistance to the normal resistance, this ratio being smaller for the purer samples with the longer mean free paths. The single crystals which were used here were probably still not quite good enough to represent samples free from all imperfections. The heat transfer from horizontal wires to the liquid helium was measured to assure that the temperature difference between sample and bath is not significant. It was found that the bubbles rising from a heater at the bottom of the Dewar simulate a forced convection which greatly increases the heat transfer coefficient and makes it independent of the temperature difference between sample and bath. It was observed that this temperature difference fluctuates by at least 10% of its value, and probably by a considerably larger amount. Measurements on a tin-coated manganin wire showed that a heating of the wire displaces the critical curve, but does not give rise to a hysteresis. Below  $3.5^\circ\text{K}$  hysteresis occurred which was not connected to the heating and which can probably be explained in terms of Ginsberg's phenomenological theory of superconductivity. A device for maintaining the temperature of the helium bath constant within a millidegree is described. (PA, v. 61, #8784)

**232. PARAMAGNETIC EFFECT IN SUPERCONDUCTORS. VI. RESISTANCE TRANSITIONS IN INDIUM WIRES**

Meissner, H., Zdanis, R.

*Physical Review*, v. 109, no. 3, pp. 681-685, February 1, 1958

The resistance of indium wires from 0.04 to 2 mm in diameter was measured as a function of current, in the temperature region from  $2.9^\circ$  to  $4.2^\circ\text{K}$ . The samples had residual resistance ratios  $r_0 = R_0^\circ\text{K}/R_0^\circ\text{C}$  of 2 to  $7 \times 10^{-4}$ . For all the samples, the transition curves measured showed a steep rise with a break at the critical current. The ratio of critical resistance to the normal resistance is examined as a function of temperature, electronic mean free path and sample diameter. Corrections are made for the temperature and magnetic-field dependence of the resistivity. (PA, v. 61, #8785)

**233. PARAMAGNETIC EFFECT IN SUPERCONDUCTORS. VII. SHAPE OF THE SUPERCONDUCTING DOMAINS**

Meissner, H.

*Physical Review*, v. 109, no. 5, pp. 1479-1485, March 1, 1958

A re-calculation of the density of the domains in the paramagnetic effect for large values of the ratio of length to diameter of the domains shows that, except for a thin layer near the surface, the density is always very small. Under these conditions the current through a single domain becomes too large to be neglected. From whatever point of view the effect of this current is considered, it will lower the value of the mean magnetic field between the domains below the value of the bulk critical field. Assuming that the same conditions persist in the absence of an external longitudinal field, the increase of the critical resistance above one-half of the normal resistance and its dependence on electronic mean free path, sample diameter, and temperature can be explained. An experimental study of the magnetic field in the center of a hollow indium wire and the longitudinal flux in a solid indium wire reveals that the paramagnetic effect gradually disappears at external fields below 0.5 A/cm. This necessitates the assumption of disturbing influences which prevent the perfect alignment of the superconducting domains. It is believed that the disturbing influences, rather than the differences between the mean magnetic field and  $H_c$ , will lead to the corrections necessary to account for the observed limiting current  $I_g$ . A detailed treatment of the size of the domains and of their distribution should be made with the use of the thermodynamics of irreversible processes. (PA, v. 61, #8786)

### 234. EFFECTS IN SUPERCONDUCTORS AT THE TRANSITION NORMAL CONDUCTIVITY-SUPERCONDUCTIVITY

Meissner, W.

*Naturwissenschaften*, v. 41, no. 19, pp. 437-440, 1954 (in German)

Continuation of experiments on the increase, in the transition region, of the longitudinal flux in wires which carry a current and are placed in an external longitudinal magnetic field. The resistance  $R$  is measured simultaneously with the flux  $\phi$ . With falling temperature  $R$  and  $\phi$  change simultaneously in steps, which are sometimes in opposite direction to the main trend. The results give further support to the explanation that the increased flux is due to helical subconducting threads (parallel to the resultant magnetic field) which caused the current to follow a similar pattern. (PA, v. 58, #2767)

### 235. THEORETICAL INVESTIGATION OF THE STABILITY OF A CYLINDRICAL PHASE-BOUNDARY BETWEEN SUPER AND NORMAL CONDUCTOR IN A CIRCULAR MAGNETIC FIELD. B. BEHAVIOR FOR VIRTUAL, FINITE, SPATIALLY-PERIODIC DISPLACEMENTS OF THE BOUNDARY

Nabaur, N., Schubert, G. U.

*Zeitschrift für Physik*, v. 151, no. 4, pp. 431-459, 1958 (in German)

It is shown that the instability which results from the London theory, if the effect of interphase surface energy is neglected (i.e.) also persists if finite displacements are considered. (PA, v. 61, #8790)

### 236. STUDY OF SUPERCONDUCTING Hg BY NUCLEAR MAGNETIC RESONANCE TECHNIQUES

Reif, R.

*Physical Review*, v. 106, no. 2, pp. 208-220, April 15, 1957

The difficulties associated with the failure of magnetic fields to penetrate inside superconductors can be overcome by the use of dense colloids consisting of particles mostly less than 500 Å in diameter. The preparation and characteristics of such Hg colloids are described and some comments are made about the experimental equipment. Experiments show that the superconducting particles give

rise to a resonance line with a Knight shift less than that of the line in the normal metal. Considerations affecting the analysis of the data are discussed at some length. Calculations are given for the resonance line shape due to a single spherical superconducting particle and also for that expected from a distribution of such particles of different sizes. A criterion is developed for determining the Knight shift from the observed superconducting line. Corrections for the microscopic broadening of the resonance line and for the bulk diamagnetism of the sample are derived. It is pointed out that the bulk magnetization curve of the superconducting colloid can also readily be measured by means of the nuclear resonance equipment. In measurements ranging from 750 to 2300 gauss the Knight shift  $K_s$  in the superconductor at 1.20°K is found to be 1.6%, or about  $\frac{1}{3}$  of its value in the normal metal. Experiments designed to elucidate the temperature dependence of the Knight shift  $K_s$  are also discussed. Some general quasi-thermodynamic comments are made to relate the Knight shift to some properties of the electron interaction energy responsible for superconductivity. Remarks based on the two-fluid model lead to some speculative predictions concerning the temperature dependence of  $K_s$ , which seem to be in at least qualitative agreement with the temperature dependence suggested by experiment. (PA, v. 60, #5353)

### 237. THE DEPENDENCE OF PENETRATION DEPTH OF A MAGNETIC FIELD INTO A SUPERCONDUCTOR ON THE STRENGTH OF A MAGNETIC FIELD

Sharvin, Yu. V.

Letter in *Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 21, p. 658, November 5, 1951 (in Russian)

The variation of the temperature derivative of penetration depth of a magnetic field in pure tin with the strength of an applied magnetic field  $H$  is found to vary as  $1 + \alpha (H/H_c)^2$  with  $\alpha = 0.28$  and independent of temperature. The method of experiment is not indicated. (PA, v. 55, #1019)

### 238. EXPERIMENTS RELATING TO THE PENETRATION DEPTHS IN SUPERCONDUCTORS

Steele, M. C.

Overseas Research Report (Department of Science, Industrial Research, London) 87/51

(Office of Technical Services, Washington, D. C., PB 101422)

Naval Research Laboratory, Washington, Report No. 3656, April 20, 1950.

Experiments have been performed to study the penetration depth in superconducting Hg, Pb and Sn. Details of the preparation of colloidal specimens and the measurement of magnetic susceptibility are presented. Using relations derived from the London theory, the observations are related to the penetration depth. For Pb the penetration depth is found to be  $(1.3 \pm 0.3) \times 10^{-5}$  cm at 4.22°K. The results for Hg and Sn are discussed qualitatively. In conclusion the limitations of the colloid method for studying penetration depth are presented. (PA, v. 54, #7903)

#### 239. MEISSNER EFFECT IN SUPERCONDUCTING ALLOYS OF INDIUM AND THALLIUM

Stout, J. W.; Guttman, L.

Letter in *Physical Review*, v. 79, p. 396, July 15, 1950

The magnetic properties associated with the superconductivity of solid solutions of 5, 10, 15, and 20 at.% Tl, in In were investigated. (CA, v. 44, 8712e)

#### 240. SUPERCONDUCTING PROPERTIES OF INDIUM-THALLIUM ALLOYS

Stout, J. W., Guttman, L.

*Proceedings of NBS Semi-centennial Symposium Low-Temperature Physics*, National Bureau of Standards, v. 519, pp. 51-60, 1951; (cf. CA, v. 47, 3068g)

Among the superconducting properties by which the behavior of alloys differs from that of pure metals are absence of the Meissner effect, broad temp., transitions in zero field, a broad range of magnetic flux penetration at const. temp., etc. These effects have been attributed to the phys. and chem. inhomogeneities in structure of an alloy with 2 or more solid phases. However, Shoenberg's work on Au<sub>2</sub>Bi and Guttman and Stout on MgTl indicated that pure, single-phase intermetallic compds., such as solid solns. of Tl in In, might behave like pure metals. Single crystal test specimens 6mm in diam. and 15cm long with 0, 5, 10, 15 and 20 at. % Tl, were prepd. X-ray exam. showed a transformation from face-centered tetragonal to face-centered cubic structure about the

middle of this range. A phase diagram for the Tl-In system is given. Most of the results given are for the 5% and 20% samples. The curve showing the behavior of the 5% Tl samples at 2.737°K., in magnetic fields up to 225 gauss, has an abrupt rise at 150 gauss. Under these conditions there is 82% Meissner effect. For the 20% Tl sample at 1.286°K.,  $H_c = 211.0$  gauss and there is 81% Meissner effect. Curves showing  $B/H_c$  and  $R/R_n$  as functions of  $H/H_c$  are given for the 5% and the 20% alloys, and also a series of temp.-resistance transition curves for 0, 5, 10, 15, and 20% Tl solid solns. in zero field. Compns. in at. % Tl and the values of  $H_0$  (in gauss) and  $T_0$  which best fit the equation  $H_c = H_0(1 - T^2/T_0^2)$ , are, resp.: 0, 285.4, 3.376°K.; 5, 277.4, 3.283; 10, 285.3, 3.357; 15, 281.7, 3.254; 20, 253.0, 3.225. Thus, the behavior of carefully prepd. single crystals of solid solns. of Tl in In up to 20 at. %, resembles that of pure metals, since the Meissner effect is large (up to 85%) and the temp. resistance transition in zero field is sharp. Full exptl. details are given of the prepn. of the samples and of the app. used for the magnetic measurements. (CA, v. 47, 7846a)

See also:

#### PERMANENT MAGNETIC MOMENTS IN A SUPERCONDUCTING SPHERE (Abstract 270)

Teasdale, T. S.

II. Experimental, B. Residual Magnetism

#### B. Residual Magnetism

#### 241. ON THE MAGNETIC PROPERTIES OF SUPERCONDUCTORS OF THE SECOND TYPE

Abrikosov, A. A.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 32, no. 6, pp. 1442-1452, 1957 (in Russian)

A study is made of the magnetic properties of the second type (massive) superconductors for which the parameter  $\kappa$  of the Ginsburg-Landau theory is greater than  $1/\sqrt{2}$ . The results explain some of the experimental data on the behaviour of superconducting alloys in a magnetic field. (PA, v. 61, #2337)

#### 242. MAGNETIC PROPERTIES OF A HOLLOW SUPERCONDUCTING LEAD SPHERE

Babiskin, J.

*Physical Review*, v. 85, pp. 104-106, January 1, 1952

The magnetic hysteresis of a hollow superconducting Pb sphere at 4.2°K has been studied by measuring the magnetic field distributions along the equatorial plane with Bi probes. After cooling in the absence of a magnetic field, the hollow sphere was found to be a perfect magnetic shield in the superconducting state. The magnetic field penetrated into the interior of the sphere when the magnetic field at the surface of the sphere exceeded the threshold value. Frozen-in fields were observed upon demagnetizing the sphere from the normal state. Upon reversing the applied field, the frozen-in field could be made to vanish, so that the sphere again became a perfect magnetic shield. The magnitude of the applied field necessary to extinguish the frozen-in field was found to be the same independent of the path of approach. The internal frozen-in fields did not change over specified ranges of the applied field, so that the existence of other equilibrium superconducting states are indicated for the hollow sphere. In the intermediate and frozen-in states, 10 to 30 min were required for the magnetic field to reach an equilibrium value. (PA, v. 55, #1812)

**243. THE ABSORPTION OF SUPERCONDUCTING TIN FOR ELECTROMAGNETIC RADIATION OF FREQUENCIES OF  $8.3 \times 10^{10}$  AND  $11.1 \times 10^{10}$  CYCLES/SECOND**

Bezuglyi, P. A., Galkin, A. A.

*Dopovidi Akademii Nauk Ukrainskoi R. S. R.*, 1957, pp. 436-438 (Russian summary)

A calorimetric procedure was used over the range of 4-1.5°K., to find the temp. function of  $R_s/R_n$  ( $R_s$  = the surface resistance in the superconductive state,  $R_n$  = same in the normal state) of a monocryst. Sn sample that had been electropolished prior to use, at the 2 frequencies. The difference between  $R_s$  and  $R_n$  is smaller at the higher frequency, but always has a finite value. For  $T \rightarrow 0^\circ$   $R_s$  does not approach zero, which can be interpreted by assuming absorption of the electromagnetic radiation by the superconducting electrons. (CA, v. 52, 5981f)

**244. THE MAGNETIC SUSCEPTIBILITY OF TIN-FLUX TRAPPED IN IMPURE SUPERCONDUCTIVE TIN**

Budnick, J. I.

*Univ. Microfilms* (Ann Arbor, Mich.), Publ. No. 16675; *Dissertation Abstracts* 16, pp. 1263-1264, 1956 (CA, v. 50, 14285b)

**245. TRAPPED FLUX IN IMPURE SUPERCONDUCTIVE TIN**

Budnick, J. I., Lynton, E. A., Serin, B.

*Physical Review*, v. 103, no. 2, pp. 286-291, July 1956

The percentage of trapped flux in cylindrical tin samples containing antimony, bismuth, or indium was measured, with particular regard to the effect of annealing. The flux was trapped by the application and removal of a large transverse magnetic field. The results do not confirm Pippard's conclusion that a marked change in flux-trapping behaviour occurs at a critical concentration of impurity. Instead it is found that all samples, whether of high- or low-impurity concentration, follow that same behaviour, namely, that the percentage of trapped flux rises steeply near the transition temperature, and that this rise decreases monotonically with annealing time. In all cases in which this rise is discernible its temperature dependence is linear with the function  $(1 - t^4)^{-1/2}$  up to  $t \geq 0.98$ , where  $t = T/T_c$ . It is believed that the binary specimens used as well as those used by Pippard have a substructure of filaments of different concentration, which trap flux when the sample is insufficiently annealed. In support of this view, extensive metallurgical evidence is cited for the existence of such a substructure, together with a crude measurement on two of the annealed specimens, which showed that the magnetic field needed to restore resistance was much higher than the threshold field of the bulk material, and that this transition was quite broad. (PA, v. 59, 6653)

**246. THE ELECTRIC RESISTIVITY AND SUPERCONDUCTIVITY OF SOME URANIUM ALLOYS AND COMPOUNDS**

Chandrasekhar, B. S., Hulm, J. K.

*Physics and Chemistry of Solids*, v. 7, pp. 259-267, 1958

Mo and Nb alloys with U exhibit peculiar resistivity anomalies. Both systems exhibit supercond. Of 10 U compds. tested, UCo, U<sub>6</sub>Mn, U<sub>6</sub>Fe, and U<sub>6</sub>Co were found to be superconducting. The significance of these results is discussed. (CA, v. 53, 6779c)

**247. THE INTERMEDIATE-STATE STRUCTURE IN CYLINDRICAL SUPERCONDUCTORS**

Cochran, J. F., Kaeser, R. S.

*Physica*, v. 23, pp. 727-745, 1957

The average magnetic moment per unit vol. of a long cylinder contg. alternate disks of superconducting and normal material has been measured in a transverse magnetic field as a function of the disk thicknesses. By the use of a laminar model of the intermediate state structure in such cylinders, it has been possible to calc. the dependence of the structure periodicity  $p$  as a function of the applied field,  $H$ , and the dimensionless ratio,  $\Delta/r_0$ , where  $r_0$  is the cylinder radius and  $\Delta$  is a parameter which characterizes the magnitude of the surface free energy at the boundary between the normal and superconducting phases. For  $0.62 H_c < H < 0.75 H_c$ ,  $p = 6.3 H_c / H \sqrt{\Delta/r_0}$ . The dependence of the magnetization on  $H$  has also been calcd., and has been used to obtain values of  $\Delta$  for Sn from magnetization and resistivity data on thin Sn wires. (CA, v. 52, 3526c)

#### 248. ADIABATIC MAGNETIZATION OF A SUPERCONDUCTING SPHERE

Dolecek, R. L.

*Physical Review*, v. 96, pp. 25-28, October 1, 1954

Measurements are reported of the temperature changes accompanying suppression of the superconductivity of a lead sphere by adiabatic magnetization. Observations were made in the temperature range 2.1°K to 4.3°K for magnetizations into the complete range of the intermediate state. The magnetic fields were applied as step functions of time, and allowance was made for the resulting eddy-current heating. After magnetization, practically complete temperature equilibrium was established in the order of 15 sec. Temperature changes observed on magnetization were in quantitative agreement with values predicted from calorimetric data and demonstrate a linear relationship between the applied magnetic field and the fraction of normal metal produced in the intermediate state. (PA, v. 57, #11083)

#### 249. CONSERVATION OF FLUX BY A SUPERCONDUCTING TORUS

Dolecek, R. L., de Launay, J.

*Physical Review*, v. 78, pp. 58-60, April 1, 1950

A superconducting torus was subjected to a magnetic field normal to the plane of the torus and the field distribution across the plane of the superconducting torus was determined experimentally. The magnetic field near the axis of the torus was found to have the same direction as the applied field, but near the inner surface of the torus

the field reversed direction in such a manner that the total flux enclosed by the torus was zero. It is concluded that the magnetic field distribution about a superconducting torus in weak magnetic fields can be adequately described by classical electrodynamics and the assumption of perfect diamagnetism. (PA, v. 53, #5949)

#### 250. QUASI-PERSISTENT CURRENTS IN RINGS COMPOSED OF SUPERCONDUCTING AND NONSUPERCONDUCTING REGIONS

Fink, H. J.

*Canadian Journal of Physics*, v. 37, pp. 474-484, 1959

A no. of rings composed of a superconductor (Pb or In) apart from a small insert of normal metal (Cu) perpendicular to the current flow have been investigated between 1.30°K. and 4.33°K. for Pb-Cu and between 1.30°K. and 3.20°K. for In-Cu. For samples with good elec. contact the decay of the magnetic field due to the current is exponential and the effective resistance increased compared with the bulk resistance of Cu by approx. 2.1 for Pb-Cu rings and by 18.5 for the In-Cu rings. Two different thicknesses of the Cu inserts (0.0125 and 0.0053 cm.) were used and the resistivity of the thin Cu insert increased with respect to the thick foil by 16% for the Pb-Cu system and by 36% for the In-Cu system. Part of this relative increase can be explained as a side effect due to electron scattering in the Cu insert. The effective resistance of the Pb = Cu rings shows a maximum at approx. 3.4°K. The resistance of the In-Cu samples decreases by about 10% between 3.2°K. and 1.3°K. The resistivity of the Cu foil when measured separately was const. for the above temp. range. For samples with "poor" electrical contact (probably due to some Cu oxide on the insert) 2 definite relaxation times were observed. For these samples the effective resistance was decreasing for decreasing currents and decreasing temps. This can be explained in terms of a rectification effect of the 2-oxide layers on the insert. The decay of the magnetic field of the ring is consistent with the decay of a current in an L-R circuit. (CA, v. 53, 10983e)

#### 251. MAGNETIC MOVEMENTS AND EDDY CURRENT DAMPING IN SPHERICAL SUPERCONDUCTORS

Fritz, J. J., Gonzales, O. D., Johnston, H. L.

*Letter in Physical Review*, v. 76, pp. 580-581, Aug. 15, 1949

Magnetic movements "frozen" into Sn spheres after various magnetic fields had been switched on and off were studied by timing torsional oscillations of the sphere suspended by a torsion wire in a small horizontal field. (PA, v. 53, #279)

**252. MAGNETIC MOMENTS AND EDDY CURRENTS IN SPHERES OF SUPERCONDUCTING TIN**

Fritz, J. J., Gonzales, O. D., Johnston, H. L.  
*Physical Review*, v. 80, pp. 894-899, December 1, 1950

Experiments have been carried out to measure the "frozen-in" moments through demagnetization from fields sufficient to destroy their superconductivity. Moments were determined with a torsion pendulum made from the spheres. Both solid Sn spheres and spheres filled with non-superconducting material were examined. Small permanent moments, fixed in magnitude and direction, and probably associated with traces of impurity, were observed for the solid spheres while considerably larger fixed moments were observed for the hollow spheres. The observed permanent moments, which amounted to 1 to 3% of the induced moments calculated for the critical field depended to a slight extent on the magnitude of the fields used to produce them and were also dependent on the size and geometry of the spheres and on the temperature. Entry into the intermediate state was evidenced by a sudden gain in the total magnetic moment when the measuring field attained a value which was close to  $\frac{2}{3}$  of the critical field,  $H_c$ . This effect is interpreted as due to the formation of regions of normal metal in the intermediate state as also are the permanent moments. The results can be explained in terms of Landau's theory of the intermediate state that postulates the presence of threads or plates of normal metal. (PA, v. 54, #2706)

**253. JUMPS IN THE DECAY OF CURRENT IN A SUPERCONDUCTING RING**

Galkin, A. A., Kan, Y. S., Lazarev, B. G.  
*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 32, no. 6, p. 1582, 1957 (in Russian)

A ring made of 1-mm diameter lead wire looped into a circle of diameter 1 cm was allowed to warm very gradually ( $\sim 0.1^\circ\text{K}$  per hour) while carrying a persistent current. Jumps of current lasting several seconds were observed from which it could be inferred that an effective

resistance of order  $10^{-11}$  ohm appeared from time to time in the ring (the full normal resistance was about  $10^{-7}$  ohm). (PA, v. 61, #1069)

**254. EXPERIMENTS ON THE MAGNETIC TRANSITION FROM THE SUPERCONDUCTING STATE TO THE NORMAL STATE**

Garfunkel, M. P., Serin, B.  
*Proceedings NBS Semicentennial Symposium Low-Temperature Physics*, National Bureau of Standards, 44, v. 519, pp. 43-44, 1952

Samples of Sn 0.15 cm. in diam. and 8 cm. long, were cast in glass tubes, converted to single crystals by suitable heat-treatment and left in the glass for testing. In the usual method of detg. and critical magnetic field necessary to produce the transition from the superconducting to the normal state, the finite length of the specimen introduces a demagnetizing effect. Hence, there may be a progressive transition, starting at the ends where the effective field is greatest. To meet this difficulty an auxiliary helix of 560 turns was wound on the middle 5 cm. with taps every cm. With this coil a supplementary field  $h$  could be applied at different parts and to different lengths of the sample. Suitable Helmholtz coils annulled the Earth's field. The magnetic susceptibility was measured by a method similar to Shoenberg's (*Proceedings of the Physical Society*, London, Cambridge, Conference Report II Low Temperature, v. 85, 1947). Four curves showing susceptibility as a function of applied field,  $H$ , are presented. The first, with  $h = 0$ , shows a sharp transition, with a total width of about 0.2 oersted, at  $H = 11.8$  oersteds. No appreciable change is produced by applying a field of 1.0 oersted over 1 cm. at the center of the sample. There is no evidence of hysteresis. However, the curves for which  $h = 5.40$  or 2.70 oersteds show hysteresis effects and indicates that the field at the central portion may exceed the critical field before the transition occurs. (CA, v. 47, 7844i)

**255. ON THE DESTRUCTION AND CREATION OF SUPERCONDUCTIVITY IN A MAGNETIC FIELD**

Ginzburg, V. L.  
*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 34, no. 1, pp. 113-125, 1958 (in Russian)

Transition from the superconducting state to the normal, and vice versa, in the presence of an external

magnetic field is considered. Critical magnetic field strengths  $H_c$ ,  $H_{c1}$ , and  $H_{c2}$  which correspond to equilibrium transition and to the boundaries of the supercooled and superheated regions respectively, are computed. Cases of small samples and of massive metals are considered. (PA, v. 61, #7039)

## 256. THE INTERMEDIATE STATE OF A HOLLOW SUPERCONDUCTING TIN CYLINDER

Gittleman, J.

*Physical Review*, v. 92, pp. 561-565, November 1953

Small bismuth probes were used to measure the magnetic field inside and outside a long, hollow, thin-walled superconducting cylinder, both as a function of the applied field and as a function of the angular position of the probes. From the variation of the magnetic field the structure of the cylinder in the intermediate state was inferred. It would appear that with the onset of the intermediate state "windows" are formed at the poles of the cylinder. The "windows," through which the applied magnetic field can penetrate into the interior of the cylinder, probably consist of the usual rapidly alternating layers of normal and superconducting metal. The parts of the cylinder around the equator remain wholly superconducting until the applied field becomes equal to the critical field, at which time the entire cylinder becomes normal. The intermediate state for the particular cylinder used in this experiment begins to appear at about  $0.3H_c$ , instead of at  $0.5H_c$ . It will be shown in a subsequent paper that this value is a function of the ratio of the inner and outside radii of the hollow cylinder. (PA, v. 57, #1334)

## 257. SUPERCONDUCTING TO NORMAL PHASE TRANSITION IN TANTALUM

Ittner, W. B.

*Physical Review*, v. 111, no. 6, pp. 1483-1487, September 15, 1958

Measurements were made of the rate at which the superconducting phase collapses radially in a hollow cylindrical tantalum specimen following the sudden application of a longitudinal magnetic field greater than the critical field. The measured transition rates confirm the hypothesis that the propagation is controlled by electromagnetic damping associated with eddy currents generated in the normal phase. The results, moreover,

may be interpreted on the basis of a theoretical treatment of the problem first published by Pippard, provided that suitable modifications are incorporated to include the thermal effects which accompany the transition. (PA, v. 62, #2350)

## 258. MAGNETIC EFFECTS OF A ROTATING SUPERCONDUCTOR

Love, W. F., Blunt, R. F., Alers, P. B.

Letter in *Physical Review*, v. 76, p. 305, July 15, 1949

An appreciable fraction of the flux of the Earth's horizontal magnetic field was "frozen in" to an Sn spheroid (symmetry axis vertical) when it became superconducting. If the spheroid was spun at 5000 rpm, however, no flux was frozen in. (PA, v. 53, #282)

## 259. MAGNETIZATION CURVES OF SUPERCONDUCTIVE TIN ALLOYS

Lynton, E. A., Serin, B.

*Physical Review*, v. 112, pp. 70-72, 1958

Magnetization of Sn contg. In, Bi, or Cd, as fine wires in transverse external field at half-crit. value shows frozen-in flux for annealed samples; this flux leaks monotonically with field reduction and vanishes in zero field. If Cd supersatn. prevails, zero field freeze-in remains. (CA, v. 53, 2804i)

## 260. DISTRIBUTION OF MAGNETIC INDUCTION IN THE INTERMEDIATE STATE OF A SUPERCONDUCTOR WITH A CURRENT

Makei, B. V.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 34, no. 2, pp. 312-315, 1958 (in Russian)

The distribution of the magnetic field in a slit cut out in the middle part of a tin cylinder with a current was measured by the bismuth-probe method. The slit was located in the diametral plane of the cylinder. The results are compared with London's and Landau's phenomenological theory of the distribution of current density in the intermediate state of a cylindrical superconductor. The existence of an intermediate state core in a superconducting wire carrying a current exceeding the critical current is directly proved by the experiments. (PA, v. 61, #7040)

**261. SUPERCONDUCTORS AT THE TRANSITION POINT NORMAL TO SUPERCONDUCTION**

Meissner, W.

*Naturwissenschaften*, v. 41, pp. 437-440, 1954

A review of recent work on study of supercond. of In monocrystals. Oscillograms of resistance of magnetic flux vs. temp. are reproduced. In the transition zone small superconductive domains appear first and gradually flow together with falling temp., the magnetic flux curves have parallel characteristics. With rising temp. the course of the change is more regular. (CA, v. 49, 9984b)

**262. SIMULTANEOUS OSCILLOGRAPHIC RECORDING OF RESISTANCE AND MAGNETIC FLUX FOR INDIUM SINGLE CRYSTALS IN THE TRANSITION REGION TO SUPERCONDUCTIVITY AT HIGH CURRENT LOADS**

Meissner, W., Doll, R.

*Zeitschrift für Physik*, v. 140, no. 3, pp. 340-358, 1955 (in German)

Detailed account and discussion of Abstract 234. (PA, v. 58, #4679)

**263. THE VOLUME CHANGE AT THE SUPERCONDUCTING TRANSITION**

Olsen, J. L., Rohrer, H.

*Helvetica Physica Acta*, v. 30, no. 1, pp. 44-66, 1957

The changes in length of polycrystalline rods of tin, lead, indium, thallium and tantalum on destruction of superconductivity by a magnetic field  $H_c$  with pressure  $p$  derived from these observations may be described within the limits of experimental error by  $\partial H_c/p = a + b(T/T_c)^2$  with the following values for  $a$  and  $b$  in units of  $10^{-9}$  Oe dyn<sup>-1</sup> cm<sup>2</sup>: Pb:  $a = -6.3$ ,  $b = -4.8$ ; In:  $a = -3.4$ ,  $b = -2.4$ ; Ta:  $a = +7$ ,  $b = -11$ . In the case of thallium  $a \simeq 0$ , and  $b$  is highly anisotropic with a value for polycrystalline material consistent with Hatton's value of +1.6. For tin  $a/(a+b) = 9.58$ . (PA, v. 60, #8636)

**264. KINETICS OF THE PHASE TRANSITION IN SUPERCONDUCTORS**

Pippard, A. B.

*Philosophical Magazine*, v. 41, pp. 243-255, March 1950

A study is made of the influence of electromagnetic effects on the speed at which a transition can occur between the normal and superconducting states of a metal in a magnetic field, and it is concluded that these are powerful enough to be the dominant factor determining the speed. Illustrative examples include the transition of a superconducting plane slab and cylinder in a field greater than critical, the destruction of superconductivity in a wire by means of a current, and the mechanism whereby the intermediate state is established. (PA, v. 53, #4096)

**265. TRAPPED FLUX IN SUPERCONDUCTORS**

Pippard, A. B.

*Philosophical Transactions of the Royal Society of London*, Series A, v. 248, no. 941, pp. 97-129, 1955

When a magnetic field is applied to a superconductor the normal state may be restored, and on removing the field the superconducting state is re-established, usually with a proportion of the field trapped in normal channels. The amount of flux trapped has been studied systematically as a function of temperature in rods of pure tin and of tin alloyed with indium up to 3%. In order to obtain significant results the specimens must be single crystals, homogenized by prolonged annealing, and having well-polished surfaces. The proportion of flux trapped is very small ( $\sim 0.1\%$ ) in pure tin, increasing steadily as the indium concentrations less than about 2.3% the proportion trapped, tends to zero as the temperature tends to the transition temperature. For greater indium concentrations there is a sharp rise in trapping to a very high value ( $\sim 50\%$ ) at the transition temperature. The trapped flux is rather firmly bound. In order to account for these results a model of the superconducting state is developed, based on the theories of London and London, and of Gorter and Casimir, and incorporating the idea of coherence. Typical processes such as spontaneous nucleation of the superconducting phase are analyzed and used to discuss the factors influencing the coalescence of adjacent superconducting domains, which is an essential part of the trapping mechanism. It is concluded that for not too great indium concentrations coalescence is achieved only through the presence of flaws, and that the sudden change in behaviour at 2.3% indium marks the beginning of spontaneous coalescence. The model appears to be capable of accounting qualitatively for most of the details of the observed behaviour. (PA, v. 58, #6153)

## 266. OBSERVATION OF NUCLEAR MAGNETIC RESONANCE IN SUPERCONDUCTING MERCURY

Reif, F.

*Physical Review*, v. 102, no. 5, pp. 1417-1418, June 1, 1956

The Knight shift of nuclear magnetic resonance in superconducting colloidal  $\text{Hg}^{199}$  is found to be about 1.5% as compared with 2.4% in the normal metal. The breadth of the superconducting resonance can be accounted for by field inhomogeneity within the mercury spheres. At 1.45°K saturation effects indicate that the nuclear relaxation time is about 0.1 sec; no saturation effects were observed in the normal state at any temperature, or in the superconducting state at 2.03°K. (PA, v. 59, #6652)

## 267. SUPERCONDUCTIVITY OF CADMIUM

Samoilov, B. N.

*Doklady Akademii Nauk, SSSR*, v. 81, pp. 791-794, 1951

Measurements below 0.6°K were made by a method consisting in recording the changes of the ohmic resistance, through the e.m.f. induced in a circuit coupled inductively with the circuit containing the sample mounted as a shunt. With a residual resistance of the sample of the order of  $10^{-6}$  ohm and a current of  $\sim 10^{-3}$  amp., the change of the signal in the induced circuit at the superconductive transition is of the order of  $10^{-5}$  v., as against a change of the potential drop on the sample itself of only  $10^{-9}$  v. The plot of the crit. magnetic field  $H_c$  as a function of the temp.  $T$  is satisfactorily described by  $H_c = H_0 [1 - (T/T_c)^2]$ , and gives the numerical data: crit. temp.  $T_c = 0.547 \pm 0.005^\circ\text{K}$ ,  $H_0 = 28.4 \pm 0.3$  gauss, and  $\nu H_0^2 / 2\pi T_c^2 = \gamma = (1.33 \pm 0.03) \times 10^{-4}$  cal./mole (degree)<sup>2</sup>. (CA, v. 46, 3821c)

## 268. PENETRATION OF MAGNETIC FIELDS THROUGH SUPERCONDUCTING FILMS

Schawlow, A. L.

*Physical Review*, v. 109, no. 5, p. 1856, March 1, 1958

Using hollow cylindrical Sn films, 700-900 Å thick subjected to 500 c/s ac fields at temperatures of from 2.2° to 3.2°K, it is found that the ratio  $H_i/H_0$  of the field detected inside the cylinder to that applied outside is about  $10^{-4}$ . On the London theory, this would imply a penetration depth  $\lambda_0$  at 0°K of about 1000 Å, twice the commonly accepted value. Using the Pippard theory, and

taking  $\lambda_0 = 510$  Å, the results imply a range of coherence  $\xi$  in the films of about 1200 Å, if the range  $\xi_0$  in bulk metal is taken to be 2500 Å, as given by the B.C.S. theory. This reasonable value for  $\xi$  is taken as evidence in favour of the non-local Pippard-B.C.S. theory. (PA, v. 61, #3143)

## 269. A MAGNETIC EFFECT IN THE TRANSITION TO SUPERCONDUCTIVITY

Steiner, K.

*Zeitschrift für Naturforschung*, 4a, pp. 271-275, July 1949 (in German)

Experiments are described in which the temp. of a Sn cylinder in a small magnetic field  $H$  parallel to the axis was lowered; a search coil connected to a ballistic galvanometer was wound round the cylinder and a current  $i$  could be passed through the cylinder. For  $i < \text{about } 1.2\text{A}$  the deflection of the galvanometer during the superconducting transition corresponded to the ejection of the flux of  $H$  from the cylinder, but for greater currents, this deflection was preceded by one in the opposite direction. Similar effects were found with In and Tl but not with Hg. No explanation is offered. (PA, v. 53, #976)

## 270. PERMANENT MAGNETIC MOMENTS OF A SUPERCONDUCTING SPHERE

Teasdale, T. S.

*Physical Review*, v. 99, no. 4, pp. 1248-1251, August 15, 1955

The magnetic flux retained by a polycrystalline sphere of pure tin has been studied by two experimental methods. It is shown that the amount of flux retained by the superconducting sphere exhibits a reproducible dependence on the temperature at which the transition is allowed to occur. The specimen shows a 99.9% Meissner effect for transitions well below the critical temperature of the specimen is constant, but the flux is not necessarily conserved when the temperature is perturbed. (PA, v. 58, #8779)

## 271. MAGNETIZATION OF TIN AT THE SUPERCONDUCTING TRANSITION

Thompson, J. C., Squire, C. F.

*Physical Review*, v. 96, no. 2, pp. 287-291, October 15, 1954

Measurements have been made of the steady-state magnetization of a tin cylinder in the presence of an external magnetic field and with an externally supplied current at

the transition to superconduction. In accord with earlier work in Germany, a longitudinal flux in excess of that caused by the external field is observed for certain conditions of external field and current. The dependence of the effect on the external parameters is given and it is shown that the metal is not in the pure superconducting state. No satisfactory theory for the effect has been found, but some numerical relationships have been computed. (PA, v. 58, #391)

## 272. MAGNETIC ABSORPTION PHENOMENA IN GERMANIUM AT LOW TEMPERATURES

Van Gerven, L., Van Itterbeck, A., De Laet, L.  
*Applied Scientific Research*, v. 7, Section B, no. 5, 1959, pp. 345-354

By means of an experimental set-up and the usual methods for magnetic resonance absorption studies, some magnetic absorption phenomena have been found and investigated in Sb-doped germanium at low temperatures ( $14^{\circ}\text{K}$ ), using relatively low radio frequencies ( $20$  to  $100\text{MHz}$ ). Ligo different absorption lines have been observed. They differ by the sign of their top and by the temperature region where they occur. One of lines is single-valued, but the other is multi-valued and shows some kind of hysteresis. Their properties and possible origins are discussed. (PA, v. 62, #8334)

## 273. MAGNETIC PROPERTIES OF A ROTATING SUPERCONDUCTOR

Wexler, A., Corak, W. S.  
*Physical Review*, v. 78, pp. 260-265, May 1, 1950

The magnetic properties of a superconductor Pb sphere have been studied through the measurement of the voltage induced between the axis and the periphery of the sphere rotated as a Faraday disc at constant speed in an axial magnetic field. Measurements were made in the range  $0$ – $10,800$  rpm. The data are consistent in all details, including critical field and the amount of frozen flux, with the properties of the frozen sphere. In the course of this work, it was found that films of colloidal graphite serve as useful resistance thermometers in the liquid He range. (PA, v. 53, #5846)

## 274. THE MAGNETIC PROPERTIES OF SOME SUPERCONDUCTING MERCURY COLLOIDS

Whitehead, C. S.  
*Proceedings of the Royal Society of London*, Series A, v. 238, pp. 175-193, December 18, 1956

Magnetization curves have been measured for fourteen colloidal mercury specimens whose average radius varied from  $3 \times 10^{-6}$  to  $15 \times 10^{-6}$  cm. For small applied fields the magnetic moment is proportional to the field and the observed temperature dependence of the slope is as predicted by the London theory. However, the dependence of these initial slopes on the average particle size cannot be explained by the London theory; the values found experimentally, extrapolated to  $0^{\circ}\text{K}$ , are numerically in better agreement with Pippard's modification of the London equation, but this does not correctly describe the temperature dependence. Measurements of the area of the magnetization curves give a mean value of  $-5 \pm 12$  A for the surface-energy parameter  $\beta$ , which means that the influence of this surface-energy is negligible for most specimens. It was found that the magnetization curves of drops small compared with the penetration depth can be scaled to have the same shape at all temperatures. This property has been explained quantitatively by a suitable modification of the two-fluid model of the superconducting state, but the theory does not seem adequate to explain some of the hysteresis features in the magnetization curves of larger drops. (PA, v. 60, #6337)

## 275. SUPERCONDUCTIVITY OF THORIUM BELOW $1^{\circ}\text{K}$ .

Wolcott, N. M., Hein, R. A.  
*The Philosophical Magazine*, v. 3, pp. 591-596, 1958

The crit. magnetic field of Th was detd. between  $0.1^{\circ}\text{K}$  and  $1.37^{\circ}\text{K}$ , the transition temp., where the initial slope of the crit. field curve is  $190$  gauss/deg. The data indicate a value of  $162$  gauss for the crit. field at abs. zero. The crit. field curve departs from a parabola near the transition temp. The electronic sp. heat  $11.1 \times 10^{-4} \text{ cal./mol.}^{-1} \text{ deg.}^{-1}$ , deduced from the magnetic measurements, is in substantial agreement with the previously determined calorimetric value. (PA, v. 61, #3947)

## C. General

## 276. ISOTOPE SHIFT OF THE TEMPERATURE OF TRANSITION OF TL INTO THE SUPERCONDUCTIVITY STATE

Alekseevskii, N. E.  
Letter in *Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 24, no. 2, pp. 240-241, 1953 (in Russian)

Presents the results of tests on two specimens of Tl, with atomic masses of  $203.34$  and  $204.94$ . The transition

temperatures obtained are  $2.403 \pm 0.003$  and  $2.392 \pm 0.003^\circ\text{K}$ , respectively. Tl is, so far, the only pure metal with a positive  $\partial T_c / \partial p$ . (PA, v. 57, #7447)

## 277. SUPERCONDUCTIVITY OF COMPOUNDS OF THE SYSTEM BISMUTH-PALLADIUM

Alekseevskii, N. E.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 23, p. 484, 1952

In alloy samples of the compn. BiPd, transition to the superconducting state was observed at about  $3.7^\circ\text{K}$ . In samples richer in Pd the transition temp. was at about  $4.0^\circ\text{K}$ . In alloys of the compn. BiPd<sub>2</sub>, the transition was blurred and variable from one sample to another. As the Pd used for the prepn. of these alloys showed no signs of supercond. between  $4.2$  and  $1.3^\circ\text{K}$ , this variable cannot be attributed to impurities in the Pd. In Bi<sub>2</sub>Pd, all-sided compression resulted in some lowering of the crit. temp.  $T_c$ , but less than in other superconductors having the same sign of  $\partial T_c / \partial p$ . (CA, v. 47, 7876b)

## 278. THE SPEED OF TRANSITION FROM THE NORMAL TO THE SUPERCONDUCTING STATE

Alexeyevski, N. E.

*Doklady Akademii Nauk* (SSSR), v. 60, no. 1, pp. 37-39, 1948 (in Russian)

The transition of a cylindrical Sn rod in a longitudinal magnetic field from the normal to the superconducting state for lowering of temp. and vice versa was studied by observing oscillographically the e.m.f. in a search coil round the specimen. On the assumption that the transition takes place by radial movement of a boundary between the phases, velocities of order 1 mm/sec were deduced, but probably a new kind of intermediate state is involved in the transition. (PA, v. 52, #1455)

## 279. THE STUDY OF BISMUTH ALLOYS IN THE REGION OF ULTRAGLOW TEMPERATURES

Alekseevskii, N. E., Gaidukov, Y. P.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 25, pp. 383-384, 1953

The magnetic moments of a series of Bi-Pt and Bi-Mg samples were detd. down to a temp. of  $0.05^\circ\text{K}$ . The fol-

lowing intermetallic compds. were studied: Bi<sub>2</sub>Pt, BiPt, Bi<sub>2</sub>Mg<sub>3</sub>, Bi<sub>2</sub>S<sub>3</sub>, Bi<sub>4</sub>Rh and also a sample of Cu<sub>3</sub>Ge. The alloy Bi<sub>2</sub>Pt becomes superconducting and the crit. temp. is detd. as  $0.1555^\circ\text{K}$ . Certain BiPt samples also exhibit supercond. having a crit. temp. of  $\approx 2.4^\circ\text{K}$ . (CA, v. 49, #5051bc)

## 280. THE STRUCTURES OF SUPERCONDUCTORS II. THE LOW-TEMPERATURE DECOMPOSITION OF THE METALLIC COMPOUND Au<sub>2</sub>Bi

Alekseevskii, N. E., Zhdanov, G. S., Zhuravlev, N. N.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 25, no. 1(7), pp. 123-126, 1953 (in Russian)

Microscopic and X-ray powder investigations established that the superconductor Au<sub>2</sub>Bi decomposes at low temperatures; this explains why a small displacement of the temperature of transition to the superconducting state is observed in specimens which have undergone hydrostatic compression. (PA, v. 57, #11077)

## 281. THE INTERMEDIATE STATE OF SUPERCONDUCTORS. II. THE RESISTANCE OF CYLINDRICAL SUPERCONDUCTORS IN TRANSVERSE MAGNETIC FIELDS

Andrew, E. R.

*Proceedings of the Royal Society of London, Series A*, v. 194, pp. 80-98, July 28, 1948. See Abstr. 2472 (1948)

The resistance of the cylinders was measured between  $1.5^\circ\text{K}$  and the superconductivity transition temperature, for cylinder radii from  $5 \times 10^{-2}\text{cm}$  to  $1.3 \times 10^{-3}\text{cm}$ . It was found that the field  $\rho H_c$ , which first caused the appearance of resistance, and which is well known to be greater than  $\frac{1}{2}H_c$ , increased with decreasing radius approx. in the manner predicted by Landau's theory. There have been considerable discrepancies between the results of previous workers concerning the temperature-dependence of  $\rho$  and on the basis of the present measurements it was possible to suggest plausible explanations of the discrepancies. It was shown that the resistance and magnetic induction in the intermediate state are closely correlated as might be expected. Using this correlation in conjunction with the magnetic behaviour predicted on the basis of Landau's theory, estimates are obtained of the surface energy at the boundary between superconducting and normal phases; it is the finite size of this energy which is responsible for the fact that  $\rho > \frac{1}{2}$ . (PA, v. 51, #2473)

**282. THE MAGNETIZATION OF SUPERCONDUCTING PLATES IN TRANSVERSE MAGNETIC FIELDS**

Andrew, E. R., Lock, J. M.

*Proceedings of the Physical Society, London, Series A*, v. 63, pp. 13-25, January 1950

The magnetization curves of thin superconducting Sn plates were measured in transverse magnetic fields in order to investigate the nature of the intermediate state in such specimens. The curves showed peak magnetizations  $\gg H_c/4\pi$ , indicating the presence of fields  $\gg$  the critical field at the edge of the plates. This effect is qualitatively similar to that predicted by Landau's theory of the intermediate state, but quantitative agreement is not obtained. Resistance measurements on thin strips of Sn in transverse fields showed that resistance only reappears for fields considerably  $>$  those required to start the destruction of superconductivity. (PA, v. 53, #2576)

**283. THE EFFECT OF ALPHA-PARTICLES ON A SUPERCONDUCTOR**

Andrews, D. H., Fowler, R. D., Williams, M. C.

Letter in *Physical Review*, v. 76, pp. 154-155, July 1, 1949

It was found that single  $\alpha$ -particles could be detected by their transient heating effect on a superconducting bolometer. The counting efficiency was comparable with that of an ionization chamber. (PA, v. 53, #284)

**284. MEASUREMENTS OF CONTACT RESISTANCE BETWEEN NORMAL AND SUPERCONDUCTING METALS**

Bedard, F., Meissner, H.

*Physical Review*, v. 101, no. 1, pp. 26-30, January 1, 1956

The contact resistance between crossed wires of Pb and Sn, Pb, Cu, Sn, and Cu, Sn and In separated by their natural oxide layers has been measured at constant temperatures as a function of current direction and magnitude. Plots of these measurements in the case of a normal and a superconducting element show the resistance at low currents to be constant and to increase suddenly above a critical current. The low current resistance generally decreased with decreasing temperature. Calculation of the radius of the current-bearing area gives radii of atomic

dimensions and shows that in some cases part of the barrier resistance disappears. Furthermore, four contacts showed an immeasurably small resistance at a function of current and temperature. No significant rectification between normal conductors and superconductors was observed. (PA, v. 59, #2897)

**285. INVESTIGATION OF ELECTRON EMISSION FROM SUPERCONDUCTORS**

Bedard, F., Meissner, H., Owen, G. E.

*Physical Review*, v. 102, no. 3, pp. 667-670, May 1, 1956

Electron emission from a superconducting tin surface at low electric field strengths was sought for. The sample was the cathode of an electron gun, which was focused on a Na(7) crystal. A photomultiplier tube and associated pulse counting equipment was used as a detector for light pulses. The measurements indicate that at a field strength of 570 V/cm the order of magnitude of each emission is less than 100 electrons/cm<sup>2</sup>-sec, under the surface conditions used. (PA, v. 59, #4439)

**286. SOME EXPERIMENTAL ASPECTS OF SUPERCONDUCTIVITY**

Boorse, H. A.

*American Journal of Physics*, v. 27, no. 1, pp. 47-57, January 1959. (PA, v. 62, #2347)

**287. SUPERCONDUCTIVITY OF LEAD**

Boorse, H. A., Cook, D. B., Zemansky, M. W.

Letter in *Physical Review*, v. 78, pp. 635-636, June 1, 1950

Determination of the transition temperature of a cylindrical Pb specimen of high purity which formed the core of a mutual inductance. The primary was actuated by 1,000 c/s ac producing a maximum field of 1.5 oersteds. The value found ( $7.224^\circ\text{K} \pm 0.02^\circ$ ) agrees well with the results previously obtained by other methods. (PA, v. 53, #7253)

**288. NEW EXPERIMENTAL RESULTS IN SUPERCONDUCTIVITY**

*Naturwissenschaften*, v. 42, no. 16, pp. 451-458, 1955 (in German)

A brief review of recent progress. (PA, v. 59, #370)

**289. SUPERCONDUCTION**

Buckel, W.

*Naturwissenschaften*, v. 42, pp. 451-458, 1955

A review of new exptl. results, discussing new superconductors, phys. properties, isotope effect, pressure and lattice effects, intermediary stages, and theory. (CA, v. 51, 3627)

**290. INFLUENCE OF CONDENSATION AT LOW TEMPERATURES ON THE ELECTRICAL RESISTANCE AND SUPERCONDUCTION OF VARIOUS METALS**

Buckel, W., Hilsch, R.

*Zeitschrift für Physik*, v. 138, no. 2, pp. 109-120, 1954 (in German)

Thin metal films were condensed from the vapor on to quartz at 4°K. Al, Zn, In, Tl, Pb, Hg, and Sn showed an abnormally high residual resistivity which disappeared on tempering. The superconducting transition temperature was variously affected; an increase by a factor 2.26 for Al and a decrease by 0.94 for Hg were the extremes. Ga and Bi were more strongly affected. Their residual resistance increases on tempering;  $T_c$  for Ga is raised from 1.07 to 8.4°K, and Bi, not normally superconducting, has  $T_c = 6.0^\circ\text{K}$ . (PA, v. 57, #10196)

**291. SUPERCONDUCTIVITY AND RESISTANCE OF TIN WITH LATTICE IMPERFECTIONS**

Buckel, W., Hilsch, R.

*Zeitschrift für Physik*, v. 132, pp. 420-442, 1952

The dependence of the elec. resistance of thin layers of Sn, produced by vapor condensation on cooled supports, upon layer thickness and nature of the support, and upon cold work was studied experimentally. On cooling of an Sn layer condensed at  $T_0$ , the transition temp., defined as the temp. of half the normal resistance before the supercond. begins, is the higher above the value of 3.7°K for solid Sn, the lower was  $T_0$  chosen. This increase is largely influenced by the nature of the support. Cold-work also raises the transition temp., but subsequent tempering returns to its previous value. (CA, v. 46, 5912g)

**292. MAGNETO-RESISTANCE EFFECTS IN THE GROUP I METALS AT HIGH FIELDS**

Chambers, R. G.

*Proceedings of the Royal Society of London, Series A*, v. 238, pp. 344-357, January 8, 1957

Measurements are reported on the resistivity and Hall coefficient of pure specimens of copper, silver and gold at 4°K in fields up to 25 kG. The theoretical form of the conductivity tensor in high fields is worked out, for arbitrary dependence of energy and relaxation time on wave-vector, and is found to be in qualitative disagreement with the experimental results. Possible causes of the discrepancy are discussed, and it is concluded that it probably arises not from quantization effects, but from the assumption in the theory that a relaxation time exists and is independent of field. (PA, v. 60, #6195)

**293. LOW TEMPERATURE PHENOMENA, REPORT ON A GENERAL RESEARCH PROJECT, 1957**

Clauser, M. U., Cooper, J. N., et al

Physical Research Laboratory, Ramo-Wooldridge Corp., General Research Program-A

This report is a brief review of the progress on the investigations of transitions between normal and superconducting states in thin films and wires being conducted at Ramo-Wooldridge.

**294. VOLUME CHANGES ASSOCIATED WITH THE SUPERCONDUCTING TRANSITION**

Cody, D. G.

*Physical Review*, v. 111, pp. 1078-1086, 1958

The length change of Pb, S, Tl, In, and Ta on superconducting transition of 1.5-4.7° (Ta excepted; frozen-in flux difficulties) was  $1-100 \times 10^{-8}\text{cm}$ . For Pb and Ta the change is relatable to variation of crit. field with pressure. For noncubic metals there is relation to crit. field-normal stress dependency. This is anisotropic for Hg, Sn, In, and Tl. Indium anisotropy is like that of Sn in magnitude, while that of Tl shows field variation with normal stress differing in sign for directions normal and parallel to the axis of symmetry of the crystal. (CA, v. 53, 58i)

**295. INVESTIGATION OF THE ATTRACTIVE FORCES BETWEEN THE PERSISTENT CURRENTS IN A SUPERCONDUCTOR AND THE LATTICE**

Condon, E. U., Maxwell, E.

*Letter in Physical Review*, v. 76, p. 578, August 15, 1949

The period of torsional oscillations of a superconducting Sn spheroid suspended by a torsion wire was studied as a function of a magnetic field applied horizontally. The observed variation could be attributed to slight sec-

ondary effects and it is concluded that the restoring torque due to the field is  $< 1\%$  of that expected if the supercurrents were rigidly fixed to the spheroid. (PA, v. 53, #278)

**296. DEMAGNETIZATION EXPERIMENTS ON CERIUM ETHYL SULFATE**

Cooke, A. H., Whitley, S., Wolfe, W. P.  
*Proceedings of the Physical Society, London*,  
v. 68B, pp. 415-421, 1955

At temps. below  $1^\circ\text{K}$ . the magnetic susceptibility is highly anisotropic. Demagnetization fields along the crystal axis show that the magnetic susceptibility in this direction passes through a max. at low temps., and that the specific heat is too large to be accounted for by magnetic dipole interaction between the magnetic ions. The behavior is attributed to antiferromagnetic coupling of the ions, possibly due to at. elec. quadrupole-quadrupole coupling. After demagnetization to a low temp. it is possible to apply a magnetic field in a direction of low susceptibility without greatly raising the temp., so that magnetic measurements can be made below  $1^\circ\text{K}$ . This has been applied to the detn. of the crit. fields of superconducting zinc and lead at temps. below  $1^\circ\text{K}$ . (CA, v. 49, 13711a)

**297. PROBLEMS CONCERNED WITH PHYSICAL PHENOMENA AT VERY LOW TEMPERATURE, ESPECIALLY THOSE RELATED TO NUCLEAR PARAMAGNETISM; STATUS REPORT (FOR THE PERIOD JULY 1, 1950 THROUGH MARCH 15, 1951)**

Daunt, J. G.  
March 14, 1951

This report covers the first nine months of progress under the contract program. The low-temperature facilities developed are described in detail and illustrated by diagrams and photographs. Brief report is made of the status of experiments in the following fields of study: the magnetic properties of superconductors below the  $1^\circ\text{K}$ ; the magnetic and thermal properties of superconductors below  $1^\circ\text{K}$ ; direct calorimetric investigations; investigations of the conditions necessary for the establishment and measurement of nuclear spin systems at temperatures  $< 0.01^\circ\text{K}$ ; investigations on the He film; and investigations of mixtures of  $\text{He}^3$  and  $\text{He}^4$ . (NSA, v. 6, #3299).

**298. SUPERCONDUCTIVITY OF TECHNETIUM**

Daunt, J. G.

*Physical Review*, v. 92, pp. 507-508, 1953

Tc is strongly diamagnetic,  $0.9-4.2^\circ\text{K}$ . Superconductive diamagnetism disappears near  $11.2^\circ\text{K}$ . The transition is broad, extending down to  $\sim 8.5^\circ\text{K}$ . This result supports Daunt's empirical correlation for superconductors. (CA, v. 455, 1403c)

**299. SOME PROPERTIES OF SUPERCONDUCTORS BELOW  $1^\circ\text{K}$ . I. TITANIUM**

Daunt, J. G., Heer, C. V.

*Physical Review*, v. 76, pp. 715-717, September 15, 1949

Magnetic measurements on Ti metal of purity 99.95% have been carried out down to  $0.3^\circ\text{K}$ . The Ti was found to be superconductive with a transition temp. of  $0.53^\circ\text{K}$ . Measurements of the magnetic threshold curve were made for which the initial slope was found to be 470 gauss per degree. (PA, v. 53, #280)

**300. SOME PROPERTIES OF SUPERCONDUCTORS BELOW  $1^\circ\text{K}$ . II. ALUMINUM AND ZINC**

Daunt, J. G., Heer, C. V.

*Physical Review*, v. 76, pp. 1324-1328, November, 1949

Magnetic measurements of the threshold curves of superconducting Al and Zn of very high purity have been carried down to  $0.3^\circ\text{K}$ . Calculations have been made therefrom of the entropy differences between the normal and superconducting states, and of the specific heats of the electron assemblies in both the normal and superconducting states. The value of the linear term for the normal electronic specific heat for Al was found to be  $2.59 \times 10^{-4} T$  cal./mole/deg and for Zn,  $1.36 \times 10^{-4} T$  cal./mole/deg. For Part III see Abstract 393. (PA, v. 53, #1769)

**301. CRITICAL FIELD MEASUREMENTS ON SUPERCONDUCTING LEAD ISOTOPES**

Decker, D. L., Mapother, D. E., Shaw, R. W.

*Physical Review*, v. 112, pp. 1888-1898, 1958

Isotope effect measurement on the superconducting crit. field in Pb has been extended from the transition temp. to  $1.28^\circ\text{K}$ . An accurate crit.-field curve is reported. It is expanded as a function of the square of the temp. and is used to calc. the thermodynamic properties of Pb. The coeff. of electronic sp. heat in the normal state and

the value of the latent heat of the supercondg. transition accord with calorimetric measurements. Below 5°K the electronic sp. heat in the superconducting state varies as  $T_4$ . Temp. dependence of crit. field of Pb is not parabolic. However, crit.-field values are hyperparabolic which is in disagreement with hitherto exhibited hypoparabolic values for all superconductors with respect to the parabola defined by the zero-field transition temp. curve. An empirical correlation exists for superconductors between deviation from parabolicity and the ratio of transition temp. to the zero-temp. Debye temp. Measurements of the isotope effect upon the crit. field below the transition temp. show small differences in the coeff. of the normal electronic sp. heat between specimens, but in general the principle of similarity in Pb is supported, as has been reported for other superconductors. (CA, v. 53, 7773d)

**302. THE INTERMEDIATE STATE OF SUPERCONDUCTORS. I. MAGNETIZATION OF SUPERCONDUCTING CYLINDERS IN TRANSVERSE MAGNETIC FIELDS**

Désirant, M., Shoenberg, D.

*Proceedings of the Royal Society of London, Series A*, v. 194, pp. 63-79, July 28, 1948

The magnetization curves of Sn and Mg cylinders were measured in transverse magnetic fields at a variety of temperatures in the superconducting range, and for various cylinder radii from  $1.8 \times 10^{-2}$  to  $1.7 \times 10^{-3}$  cm. As the radius was reduced the curve departed more and more from the simple form to be expected for an infinite cylinder of large radius, and the details of the departures agree qualitatively with the predictions of Landau's theory of the intermediate state. The experiments show also that the sharp drop of magnetization corresponding to entry into the intermediate state coincides closely with the appearance of resistance. Detailed comparison with Landau's theory yields estimates of the surface energy at a boundary between normal and superconducting phases at the various temperatures. (PA, v. 51, #2472)

**303. EXPERIMENTS ON THE SUPERCONDUCTIVITY OF CONTACTS**

Dietrich, I.

*Zeitschrift für Physik*, v. 133, no. 4, pp. 499-503, 1952 (in German)

Contacts between Ta electrodes covered with  $\text{TiO}_2$  or  $\text{CeO}_2$  layers 15 to 40 Å thick become superconductive.

The dependence of the transition curves on thickness and current is investigated. (PA, v. 56, #4813)

**304. THE TRANSITION TO SUPERCONDUCTIVITY**

Doidge, P. R.

*Philosophical Transactions, A*, v. 248, no. 954, pp. 553-573, 1956

Magnetic and electrical measurements have been made of the effect of impurity on the transitions to superconductivity in tin. Reproducible results were obtained only with well-annealed monocrystalline specimens. Solution of up to 6% indium in pure tin decreases the electronic mean free path  $l$  from about  $3 \times 10^{-3}$  to  $\times 10^{-6}$  cm, and over this range magnetic measurements show that there is only a small depression of the transition temperature  $T_c$  and a small alteration in the critical field curve of  $H_c$  and  $T$ . Electrical measurements show that if  $l > l_c$ , where  $l_c = 8 \times 10^{-6}$  cm, the resistance transitions are sharp and almost concurrent with the magnetic transitions. However, if  $l < l_c$  superconducting nucleation apparently occurs, since a state of partial superconductivity exists with zero resistance, but no exclusion of magnetic induction, in fields greater than  $H_c$  but less than  $H'_c$ , where it has been found that at any one temperature  $H_c/H'_c = 1/l_c$ . This relation describes in broad outline the dependence of  $H'_c$  on  $l$  and temperature, although the interpretation of the results is complicated by considerable broadening of the resistance transitions and the appearance of a sensitive non-linear dependence on the measuring current of the temperature of nucleation. These complicating effects may wholly or partly be due to inhomogeneities in indium concentration. The concept of a range of coherence  $\xi$  of the superconducting phase is used in formulating thermodynamic conditions for the formation in a magnetic field of superconducting nuclei with cylindrical and spherical symmetry. It is shown that the main features of superconducting nucleation in homogeneous tin-indium alloys can be accounted for if

$$\xi = \frac{2\lambda_0 l}{l_c(1-t^2)^{1/2}}$$

where  $t = T/T_c$  and  $\lambda_0$  is the penetration depth at 0°K. The implication that  $\xi$  greatly exceeds  $l$  just below  $T_c$  is supported by a consideration of the sharpness of resistance transition and the shape of the critical field curve near  $T_c$ . The formula for  $\xi$  resembles that given in Pippard's phenomenological theory of superconductivity (1953). (PA, v. 59, #7430)

### 305. ADIABATIC MAGNETIZATION OF A SUPERCONDUCTOR

Dolecek, R. L.

*Physical Review*, v. 82, p. 102, April 1, 1951

It is shown experimentally that no temperature changes occur for adiabatic application of magnetic fields less than  $\frac{1}{2} H_c$  to a tin sphere. (PA, v. 54, #5422)

### 306. FOURTH ANNUAL PROGRESS REPORT ON NUCLEAR AND ELECTRONIC PARAMAGNETISM AND LOW TEMPERATURE STUDIES

Dunnington, F. G.

September 1, 1950

"Low Temperature Studies," by B. Serin and C. A. Reynolds. The studies using the technique of superimposing alternating and direct current on a superconductor and observing the average electromotive force as a function of the amplitude of the alternating current have been brought to conclusion. Studies on the superconductivity of mercury isotopes and on low-temperature resistance minima in metals are reported. (NSA, v. 5, #1029)

### 307. COMMENTS ON AN EXPERIMENT WITH PERSISTENT CURRENTS

Edwards, M. H., Rogers, D. H.

*Canadian Journal of Physics*, v. 34, no. 6, pp. 619-621, June 1956

Discusses an experiment by Collins (1955) on persistent currents in a superconducting lead tube and shows that his results agree with elementary theory. (PA, v. 59, #6651)

### 308. SUPERCONDUCTING ELEMENTS

Eisenstein, J.

*Review of Modern Physics*, v. 26, pp. 277-291, 1954

A review with 75 references. (CA, v. 49, 2797e)

### 309. CREATION AND GROWTH OF SUPERCONDUCTING NUCLEI

Faber, T. E.

*Letter in Nature*, v. 164, pp. 277-278, August 13, 1949

A Sn cylinder can be kept in the normal state even in magnetic fields slightly below critical (supercooling) owing to the absence of a superconducting nucleus. It

was found that such a nucleus can be created by lowering the field locally, and it then spreads along the rod at a speed of order 10 cm/sec which increases with the degree of supercooling. (PA, v. 53, #977)

### 310. THE PHASE TRANSITION IN SUPERCONDUCTORS. I. NUCLEATION

Faber, T. E.

*Proceedings of the Royal Society of London*, Series A, v. 214, pp. 392-412, September 23, 1952

A detailed study of "supercooling" in Sn rods has confirmed the hypothesis that this is caused by the difficulty of forming a nucleus of the superconducting phase. The experiments show that when nucleation does occur it only happens at certain flaws in the metal, which have been proved to lie at the surface and to be between  $10^{-4}$  and  $10^{-3}$  cm in size. These flaws do not appear to be necessarily associated with surface conditions, impurity content, or crystal boundaries. Any handling of the specimen affects them, but simply warming it to room temperature often does not, in which case the supercooling observed in separate experiments is reproducible. The degree of supercooling  $\phi_1$ , defined as  $(H_c^2 - H_1^2)/H_c^2$ , where  $H_1$  is the field at which nucleation is first possible, varies in magnitude from flaw to flaw (0.8 is the largest value found), but it always depends on temperature in the same way, rising as  $T \rightarrow T_c$ . The supercooling can sometimes be increased by applying a high field to the specimen beforehand, indicating that some of the flaws can be temporarily destroyed by such treatment. The behaviour of the flaws can be accounted for if they are assumed to be domains where the interphase surface tension has become negative, perhaps as the result of local lattice distortion produced by dislocations. Using a simple model based on this picture the magnitude and temperature dependence of  $\phi_1$  have been explained quantitatively in terms of the characteristic flaw size and the positive surface tension in the undistorted metal (as estimated from work on the intermediate state.) Slight superheating (up to 1.5% of  $H_c$ ) has also been observed. (PA, v. 55, #8216)

### 311. THE PHASE TRANSITION IN SUPERCONDUCTORS. II. PHASE PROPAGATION ABOVE THE CRITICAL FIELD

Faber, T. E.

*Proceedings of the Royal Society of London*, Series A, v. 219, pp. 75-88, August 11, 1953

Detailed measurements have been made of the rate at which the superconducting phase collapses radially in cylindrical rods of tin, when they are suddenly subjected to a magnetic field greater than the critical. This is probably the simplest example of phase propagation in superconductors. The results in most respects confirm the theory of Pippard and Lifshitz (Abstract 135), according to which the propagation is controlled by an electromagnetic damping associated with the setting up of eddy currents. This theory explains in detail the way in which the rate of propagation depends on specimen radius and conductivity, and on field strength; its only failure is at the higher temperatures, where the magnitude of the rate of propagation tends to be slightly less than the theory predicts. Other factors besides eddy currents which might be retarding the transition are latent heat, the interphase surface energy, and a finite relaxation time governing the destruction of superconductivity by a magnetic field; but none of these proves altogether adequate to account for the discrepancy mentioned. The experiments provide evidence that the relaxation time is less than  $0.2 \mu\text{sec}$  in tin. (PA, v. 56, #6806)

**312. THE PHASE TRANSITION IN SUPERCONDUCTORS. III. PHASE PROPAGATION BELOW THE CRITICAL FIELD**

Faber, T. E.

*Proceedings of the Royal Society of London, Series A*, v. 223, pp. 174-194, April 22, 1954

If a superconducting nucleus is created at one end of a long rod of supercooled tin, it grows down to the other end with a velocity,  $v$ , of the order of 10 cm/sec. This process has been studied experimentally by winding search coils round the specimens to record the progressive expulsion of the longitudinal magnetic field; in particular  $v$  has been measured as a function of field strength and temperature, for a number of specimens of varying radius, conductivity and surface condition. It is shown that  $v$  is governed by the progress of a thin superconducting filament that shoots out from the nucleus along the surface of the specimen. Subsequently this filament closes up to form a sheath of the superconducting phase, leaving some flux enclosed which takes several seconds to escape; however, these later stages of the transition are only briefly discussed. A quantitative theory is developed to account for the rate of advance of the original filament, by considering the conditions for the conservation of energy

during propagation. It is assumed that the two controlling factors are the interphase surface tension and the electromagnetic damping effect of the eddy currents set up in the normal phase ahead of the filament. The theory is complicated by an interesting phenomenon analogous to the anomalous skin effect, which is observed when the electronic mean-free path becomes comparable with the filament thickness; a dimensional analysis of the results reveals that the eddy currents may behave "classically," "anomalously" or somewhat between the two, depending on the conditions of the experiment. Only in the anomalous region is the theory completely successful, but its failure elsewhere can be traced to limitations in the rather simple model which is considered. Values of the interphase tension are deduced from the experimental data; these are in agreement with previous estimates based on intermediate state work, but they are more extensive and probably more reliable. They are briefly compared with the predictions of Ginsburg and Landau (1950) and Pippard (1951, 1953). (PA, v. 57, #5635).

**313. THE SURFACE RESISTANCE OF NORMAL AND SUPERCONDUCTING TIN AT**

36,000 Mc/sec

Fawcett, E.

*Proceedings of the Physical Society, London*, v. 66A, pp. 1071-1072, 1953

An app. was constructed to investigate the surface resistance of metals at liquid-He temp. Plane single crystals of tin were used, with the current flow in one direction of the plane, so that the anisotropy can be further studied. (CA, v. 48, 6757d)

**314. SUPERCONDUCTING ENERGY GAP INFERENCES FROM THIN-FILM TRANSMISSION DATA**

Forrester, A. T.

*Physical Review*, v. 110, no. 3, pp. 776-778, May 1, 1958

It is shown that the infrared transmission results of Glover and Tinkman (Abstract 321) do not determine the form of the superconducting conductivity  $\sigma(\omega)$  very closely; in particular, they are compatible with a form of  $\sigma(\omega)$  which does not imply the existence of an energy gap. (PA, v. 61, #5924)

### 315. ABSORPTION OF AN ELECTROMAGNETIC FIELD BY SUPERCONDUCTORS

Galkin, A. A., Bezuglyi, P. A.

*Dopovidi Akademii Nauk Ukrainskoi*, R. S. R., pp. 178-181, 1954

The high-frequency resistance of Sn was measured on a single crystal over a frequency range  $2.5 \times 10^{10} - 3.5 \times 10^{10}$  cycles/sec. London's 2-liquid model describes the relation between the surface resistance of the superconductor and the frequency or temperature. (CA, v. 49, 12115g)

### 316. DESTRUCTION OF SUPERCONDUCTIVITY BY AN ALTERNATING CURRENT

Galkin, A. A., Bezuglyi, P. A.

*Journal of Experimental and Theoretical Physics*, USSR, v. 20, pp. 1145-1146, December 1950 (in Russian)

In earlier experiments it was shown that if a dc current  $I_1$  and an ac current of amplitude  $I_0$  were superimposed in a Tl wire, the p.d. across the wire reached a maximum value  $V$  for  $I_0 + I_1 = I_c$ , the current just sufficient to destroy superconductivity; the value of  $V$  for given  $I_0$  was found to fall off at frequencies of the order of  $10^6$  c/s. Recent experiments on Sn by Serin, Feldmeier and Garfunkel showed instead that  $V$  increased with frequency at fairly low frequencies. It was suggested that this was due to the conditions becoming adiabatic rather than isothermal, and this was confirmed by showing that the effects observed by Serin, et al, could be reproduced if the Sn wire was in a glass envelope, but not if it was in direct contact with the liquid He bath. (PA, v. 54, 9488)

### 317. SOME PECULIARITIES OF THE TRANSITION INTO THE SUPERCONDUCTING STATE. I.

Galkin, A. A., Ya. S. Kan, Lazarev, B. G.

*Journal of Experimental and Theoretical Physics*, USSR, v. 20, pp. 865-870, October 1950 (in Russian)

The resistance of a Sn wire was recorded as the temperature was slowly ( $5 \times 10^{-4}$ °K per min) and smoothly lowered through the transition temperature and was found to show violent changes of an irregular character in the transition region (about  $2 \times 10^{-3}$ °K wide). These irregularities disappeared if a sufficiently large longitudinal magnetic field was applied. The effects are ascribed to the complicated kinetics of growth of superconducting nuclei formed in the transition region. (PA, v. 54, #9486)

### 318. SOME PECULIARITIES OF THE TRANSITION INTO THE SUPERCONDUCTING STATE. II.

Galkin, A. A., Lazarev, B. G., Bezuglyi, P. A.

*Journal of Experimental and Theoretical Physics*, USSR, v. 20, pp. 987-994, November 1950 (in Russian)

Three experiments are described: (1) Oscillograms were taken of the e.m.f. in a coil wound on a Sn rod in a longitudinal ac field large enough to destroy superconductivity; (2) the reduction of a persistent current in a superconducting Sn ring was studied after an ac field (frequency  $10^2$  to  $10^4$  c/s) of amplitude  $H_c$  had been applied round the ring. The reduction is only partial due to the skin effect; (3) the destruction and restoration of superconductivity in a Sn rod by an ac field superimposed on a steady field was studied in nearly adiabatic conditions. It is concluded that the boundary between normal and superconductive phases can move with a velocity of at least  $10^3$  cm/sec. (PA, v. 54, #9487)

### 319. EFFECT OF HYDROSTATIC PRESSURE ON THE SUPERCONDUCTING TRANSITION OF TIN

Garber, M., Mapother, D. E.

*Letter in Physical Review*, v. 94, p. 1065, May 15, 1954

Pressures up to 100 atmospheres were applied through liquid helium and  $\Delta H_c$  measured between 3.45°K and 3.70°K. At  $T_c \partial T_c / \partial p$  was found to be  $4.40 \pm 0.20 \times 10^{-6}$ °K atmos<sup>-1</sup>, slightly lower than found by Kan, Lazarev, and Sudovstov (*Journal of Experimental and Theoretical Physics*, USSR, v. 18, p. 825, 1948). The discrepancy is thought to be due to slight irreversible effects which were not taken into account in the earlier work. (PA, v. 57, #9260).

### 320. THE FORMATION OF A BOUNDARY BETWEEN NORMAL-CONDUCTING AND SUPERCONDUCTING METAL

Garfunkel, M. P., Serin, B.

*Physical Review*, v. 85, pp. 834-840, March 1, 1952

An experiment is described in which a superconducting sample is arranged so that part of it is in the normal state and part of it is superconducting. The boundary surface is thus a single, large area rather than the complicated boundaries that exist between normal and super-

conducting regions when a sample is in the intermediate state. A large difference is found between the magnetic field at which the superconducting-normal state transition occurs and the magnetic field at which the normal state-superconducting transition occurs. These results are in agreement with the thermodynamic theory of the phase transition. The thermodynamic theory, coupled with an assumption about the nature of the surface energy between superconducting and normal metal, is used to show how the hysteresis determines the ratio of this surface energy to a characteristic dimension of the superconductor. A measure of this ratio is given in the temperature region between 3.37°K and 3.68°K for superconducting tin. (PA, v. 55, #3601)

### 321. CONDUCTIVITY OF SUPERCONDUCTING FILMS FOR PHOTON ENERGIES BETWEEN 0.3 AND 40 $kT_c$

Glover, R. E., III, Tinkman, M.

*Physical Review*, v. 108, no. 2, pp. 243-256,  
October 15, 1957

Far infrared and millimetre microwave transmission experiments through thin superconducting lead and tin films are reported. The frequency range covered corresponds to photon energies from 0.3 to 40  $kT_c$ . The measurements include the previously unexplored frequency region in which a superconductor changes from an essentially lossless conductor to a normal one. By suitable analysis the effective complex conductivity of the films is obtained from the transmission data. For thin superconducting films it was shown that  $(\sigma_1(\omega) - i\sigma_2(\omega))/\sigma_N$  is, to a good approximation, a universal function of the reduced frequency ( $\hbar\omega/kT_c$ ) being independent of film resistance, thickness, degree of anneal, and material (for the two metals tried). At  $T = 0$ ,  $\sigma_1$  appears to be very small (or zero) for photon energies below roughly 3  $kT_c$ . Starting at 3  $kT_c$ ,  $\sigma_1$  rises rapidly and reaches its limited value of  $\sigma_N$  at about 20  $kT_c$ . This behavior suggests a gap of width  $\approx 3 kT_c$  in the electronic excitation spectrum of the superconducting state. At  $T = 0$  and for photon energies considerably smaller than 3  $kT_c$ ,  $\sigma_2/\sigma_N \approx \alpha kT_c/\hbar\omega$ , with  $\alpha = 3.7 \pm 0.7$  for both Sn and Pb. The frequency dependence is in agreement with the London theory. This theory, however, would not predict that the results for Pb and Sn should be the same and, moreover, it would give values of  $\alpha \sim 100$  times too large. The Pippard nonlocal theory predicts the type of universal dependence found,

but with  $\alpha = 6.7$ . For photon energies of the order of 3  $kT_c$ , a polarizability term  $\sigma_2(\omega)$  near 3  $kT_c$ , becomes important and tends to cancel the  $1/\omega$  term in  $\sigma$ . As a result,  $\sigma_2$  is reduced to a small value for photon energies above 5  $kT_c$ . Some information about temperature dependence of the complex conductivity has also been obtained. (PA, v. 61, #5923).

### 322. OCCURRENCE OF SUPERCONDUCTIVITY BELOW 1°K.

Goodman, B. B.

*Proceedings of NBS Semi-centennial Symposium on Low-Temperature Physics*, National Bureau of Standards, v. 519, pp. 71-72, 1952

Various pure metals were cooled to about 1°K. by the method described by Mendoza. The summary of the results is as follows:

Element	$\rho/\rho_{273}$	$T_c$ (°K)	$H_c$ (gausses)	(cal $\gamma$ mole $^{-1}$ deg $^{-2}$ )
Al	$18 \times 10^{-4}$	1.197	106.0	$2.95 \times 10^{-4}$
Cd	3.1	0.560	28.8	1.28
Ga	1.0	1.103	50.3	0.91
Zn	14	0.905	52.5	1.16
Ru	150	0.47	46	3.0
Os	400	0.71	65	2.7

where  $\rho/\rho_{273}$  is the ratio of the resistance of the normal metal at  $T_c$  to that at 273°K. and is guide to the quality,  $T_c$  is the transition temp.,  $H_c$  the crit. magnetic field and  $\gamma$  is the electronic sp. heat calcd. from the data. The following metals were not superconducting down to the Kelvin temps. indicated: Li 0.08°, Na 0.09°, K 0.08°, Ba 0.15°, Y 0.10°, Ce 0.25°, Pr 0.025°, Nd 0.25°, Mn 0.15°, Co 0.12°, Pd 0.10°, Ir 0.10°, Pt 0.10°. (CA, v. 47, 2562d)

### 323. SUPERCONDUCTIVITY OF URANIUM

Goodman, B. B., Shoenberg, D.

*Letter in Nature*, v. 165, pp. 441-442, March 18, 1950

Two specimens of U became superconducting at 0.75°K, while others (less pure) became superconducting at about 1.3°K. in agreement with previous work of Justi. Some observations of the magnetic field required to destroy superconductivity and of the specific heat are also reported. (PA, v. 53, #4998)

### 324. CHANGE IN THE SHEAR MODULUS OF TIN AT THE TRANSITION FROM THE NORMAL CONDUCTING TO THE SUPERCONDUCTING STATE

Grassman, P., Olsen, J. L.

*Helvetica Physica Acta*, v. 28, pp. 24-32, 1955

The results were obtained by an optical method. They are represented by  $\Delta G/G = 3.5 \times 10^{-6} (1 - t^4)$ , where  $G$  is the shear modulus;  $t = T/T_c$ ,  $T_c = 3.73^\circ\text{K}$ ., the transition point. The temp. range extends downward to  $T = 1.7^\circ\text{K}$ . (CA, v. 49, 12894e)

### 325. THRESHOLD CURRENT VALUES FOR SUPERCONDUCTING LEAD-BISMUTH ALLOYS IN EXTERNAL MAGNETIC FIELDS

Grassman, P., Rinderer, L.

*Helvetica Physica Acta*, v. 27, pp. 309-312, 1954

(Eidg. Tech. Hochschule, Zurich, Switzerland)

The alloys contained 10% Bi and were studied at  $4.2^\circ\text{K}$ ., in both transverse and longitudinal fields. The behavior was very different from that with pure metals but it agreed with theoretical predictions concerning current and wire diam., at fields up to 2000 gauss. (CA, v. 49, 16b)

### 326. THE DESTRUCTION OF SUPERCONDUCTIVITY OF THIN FILMS BY A MAGNETIC FIELD

Gurevich, A. V.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 27, no. 2, pp. 197-207, 1954 (in Russian)

It is shown that the treatment of Ginsburg and Landau in applying their theory to this problem (Abstract 89) is correct only for the parameter  $\kappa = 0$ , where  $\kappa = \sqrt{2eH_c} \lambda^2 / hc$  ( $H_c$  = bulk critical field,  $\lambda$  = penetration depth). The correct formulae for non-vanishing  $\kappa$  are deduced and turn out to be practically identical with those for  $\kappa = 0$  if the actual values of  $\kappa$  for Sn and In are used. It is pointed out that Zavaritski (Abstract 434) used an unjustified approximation in deducing  $\lambda_0$  from his thick-film data and that a correct application of the theory gives good agreement between  $\lambda_0$  as deduced from both thick- and thin-film data. This re-evaluation gives  $\lambda_0 = 6.5 \pm 0.6 \times 10^{-6}$  cm for Sn and  $6.4 \pm 0.5 \times 10^{-6}$  cm for In. Closely similar values are deduced from Lock's data (Abstract 420) for critical fields of thin films, though for Sn Lock obtained an appreciably lower value from the film magnetizations. (PA, v. 58, #3788)

### 327. SUPERCONDUCTIVITY IN MgTl AND LiBi

Guttman, L., Stout, J. W.

*Proceedings, NBS Semi-centennial Symposium Low-Temperature Physics*, National Bureau of Standards, v. 519, pp. 65-67, 1952

A rod of MgTl, approx. 6.2 mm. in diam. and 85 mm. long was prepd. by fusing Mg and Tl in proper proportions in a graphite crucible. Analysis indicated the possibility of a slight excess of pure Tl. Measurements made with the app. previously described showed sharp transitions and expulsion of field which are in marked contrast to typical "alloy behavior." The temps. and the crit. fields, observed and calcd. by  $H_c = 220.0 (1 - (T/2.745)^2)$  are, resp.:  $1.291^\circ\text{K}$ .,  $163.3 \pm 2\%$ , 171.2; 2.083,  $93.8 \pm 2\%$ , 93.4; 2.422,  $48.3 \pm 1\%$ , 48.8; 2.509,  $35.2 \pm 2\%$ , 36.3; 2.564,  $28.2 \pm 1\%$ , 28.2. A sample of a-LiBi was found to be superconducting but the transitions were broad. The zero-field transition temp. was estd. as  $2.47^\circ\text{K}$ . (CA, v. 47, 7846e)

### 328. AN ANOMALOUS CRITICAL CURRENT EFFECT IN SUPERCONDUCTING NbN

Haley, F. C., Andrews, D. H.

*Physical Review*, v. 89, pp. 821-823, February 15, 1953

Observations have been made of thirty transitions from the normal to the superconducting state occurring in four samples of NbN over a range of current from 0.01 mA to 10 mA. The samples were made from 5 and 10 mil diameter wire and from  $\frac{1}{4}$  to 1 mil thick sheets. For  $H_l > 100$  oersted evidence was found for the usual parabolic relation between  $T$  and  $H_l$ , the field produced at the surface of the wire by currents just sufficient to make  $R = 0.5 R_n$ ; but for  $H_l < 100$  oersted the curve tailed off to higher values of temperature, approaching the axis for  $H_l = 0$  tangentially several tenths of a degree above the value of  $T_0$  where it is normally assumed to intersect the axis as a straight line. This is further evidence to support Mendelssohn's suggestion of a sponge-like structure for superconducting alloys. (PA, v. 56, #2468)

### 329. SUPERCONDUCTING SILICIDES AND GERMANIDES

Hardy, G. F., Hulm, J. K.

*Physical Review*, v. 89, p. 884, 1953

Silicides and germanides were prepd. by sintering compressed pellets several hours in a He atm. at  $1500^\circ$  and

1000°, resp. The temps. (°K) at which the compds. became superconducting are:  $V_3Si$ , 17.0;  $V_3Ge$ , 6.0;  $Mo_3Si$ , 1.30;  $MoSi_{0.7}$ , 1.34;  $MoGe_{0.7}$ , 1.20;  $WSi_{0.7}$ , 2.84;  $ThSi_2$ , 3.16. Compds. that are not superconducting down to 1.2°K are:  $Ti_5Si_3$ ,  $Ti_5Ge_3$ ,  $TiSi$ ,  $TiSi_2$ ,  $TiGe_2$ ,  $Zr_4Si$ ,  $Zr_2Si$ ,  $Zr_3Si_2$ ,  $Zr_4Si_3$ ,  $Zr_6Si_5$ ,  $ZrSi$ ,  $ZrSi_2$ ,  $VSi_2$ ,  $NbSi_{0.6}$ ,  $NbSi_2$ ,  $TaSi_2$ ,  $Cr_3Si$ ,  $Cr_3Si_2$ ,  $CrSi$ ,  $CrSi_2$ ,  $WSi_2$ , and  $MoSi_2$ . In the isomorphous series  $V_3Si$ ,  $V_3Ge$ ,  $Mo_3Si$ ,  $Mo_3Ge$ , and  $Cr_3Si$ , which have a cubic structure with  $a$  positions similar to those in  $\beta$ -W, only the Cr compd. remained normal down to 1.2°K. When 0.1 of the V in  $V_3Si$  was replaced by Ti, Zr, Nb, Mo, Cr, or Ru, or 0.1 of the Si by B, C, Al, or Ge, the transition temp. was depressed by as much as 10°. (CA, v. 47, 8432e)

### 330. THE SUPERCONDUCTIVITY OF SOME TRANSITION METAL COMPOUNDS

Hardy, G. F., Hulm, J. K.

*Physical Review*, v. 93, pp. 1004-1016, March 1, 1954

About eighty transition metal compounds comprising borides, carbides, nitrides, oxides, silicides and germanides of metals of Groups 4A, 5A, and 6A were tested for superconductivity down to 1.20°K, using a magnetic method. Among the specimens were most of the known compounds of the above type not examined magnetically for superconducting behaviour by previous workers, and in all cases the structures were checked by X-ray diffraction analysis. The following eleven new superconductors were discovered, with the transition temperatures (°K) shown in parentheses:  $W_2B$  (3.10°),  $Nb_2C$  (9.18°),  $Ta_2C$  (3.26°),  $Nb_4N_3$  (7.2°),  $V_3Si$  (17.1°),  $V_3Ge$  (6.01°),  $Mo_3Si$  (1.30°),  $Mo_3Ge$  (1.43°),  $\alpha$ - $ThSi_2$  (3.16°),  $\beta$ - $ThSi_2$  (2.41°) and  $W_3Si_2$  (2.84°). These compounds include the first superconducting germanides,  $V_3Ge$  and  $Mo_3Ge$ , which, together with  $V_3Si$  and  $Mo_3Si$ , crystallize in the cubic  $\beta$ -tungsten structure. The transition temperature of  $V_3Si$  is apparently the highest known for any binary superconducting compound. (PA, v. 57, #4556)

### 331. SUPERCONDUCTIVITY OF LEAD SULFIDE

Hatton, J., Rollin, B. V., Seymour, E. F. W.

*Proceedings of the Physical Society, London*, v. 64A, p. 667, 1951

Two pure specimens of galena examined down to 1°K failed to exhibit superconductivity. (CA, v. 146, 9920c)

### 332. NUCLEAR RELAXATION IN SUPERCONDUCTING ALUMINUM

Hebel, L. C., Slichter, C. P.

*Physical Review*, v. 107, no. 3, pp. 901-902, August 1, 1957

Measurements were made on the signal from the normal metal, by re-applying a field  $> H_c$  after allowing relaxation to occur in the superconducting state. At 0.94°K ( $T/T_c \sim 0.8$ ), the ratio  $R_s/R_n$  of relaxation rates in the superconducting and normal states was about 2. Using Hg, Reif has found  $R_s/R_n \sim 0.1$  at  $T/T_c = 0.27$ . This change in  $R_s/R_n$  can be explained using an energy-gap model, but would be unexpected on a two-fluid model. The Bardeen-Cooper-Schrieffer model, with parameters chosen to give  $R_s/R_n = 2$  at  $T/T_c = 0.8$ , gives  $R_s/R_n = 0.13$  at  $T/T_c = 0.27$ . (PA, v. 61, #192)

### 333. INVESTIGATION OF THE SUPERCONDUCTIVITY OF HAFNIUM

Hein, R. Z.

*Physical Review*, v. 102, pp. 1511-1518, 1956

The magnetic susceptibilities of 2 polycryst. rods of Hf (I and II) were observed at 4.22-0.88°K. The elec. resistance of these specimens was also observed from room temp. to 0.08°K. Although the magnetic measurements indicated unambiguously that no superconducting transition occurred, the elec. resistance decreased at  $\sim 0.19^\circ K$ . for I and  $0.28^\circ K$ . for II. The resistance did not fall to zero but remained finite down to the lowest temps. obtained. The temp. at which this decrease occurred was sensitive to an externally applied magnetic field. Crit. field data for I indicated a  $(dH/dT)T = T_c$  of 450 gauss/deg. Magnetic and ele. measurements of one specimen, after an anneal, indicated no marked change in these measured quantities. Both specimens had a purity of 98.92%. The magnetic susceptibility of lathe turnings of Hf,  $\sim 96\%$  pure, showed a superconducting transition at 0.173°K. A few crit. field points were obtained. They give the value of  $(dH/dT) = dT_c$  of 130 gauss/deg. A consideration of all the available data on the supercond. of Hf shows that pure Hf is probably not a superconductor down to 0.08°K. (CA, v. 50, 14283f)

### 334. SEARCH FOR LOW-TEMPERATURE SUPER-CONDUCTIVITY IN GRAPHITE COMPOUNDS

Hennig, G., Meyer, L.

*Physical Review*, v. 87, p. 439, 1952; cf. *CA*, v. 46, 337 e

Graphite and graphite compounds with Br, K, Ca, B, ammonium, and bisulfate were investigated for superconductivity down to 1.25°K. None became superconducting. (*CA*, v. 46, 9403g)

### 335. ELECTROMAGNETIC INDUCTION IN A SUPERCONDUCTOR

Houston, W. V., Squire, C. F.

Letter in *Physical Review*, v. 76, pp. 685-686, September 1, 1949

A Pb ellipsoid was spun at from 3,000 to 9,000 rpm in a vertical field of 30 to 70 gauss. The e.m.f. between two points on the surface fell from its expected value when the Pb was normal to less than 5% of this value when the Pb became superconducting. Preliminary results (*Science*, v. 109, p. 439, 1949) which suggested no reduction of e.m.f. in the transition were shown to be due to heat generation at the bearings which caused the temp. to be above that of the liquid He bath. (See also Abstract 402) (*PA*, v. 54, #2463)

### 336. ELECTROMAGNETIC FORCES ON A SUPERCONDUCTOR

Houston, W. V., Muench, N.

*Physical Review*, v. 79, pp. 967-970, September 15, 1950

Measurements of the eddy current damping of the rotational oscillations of a Sn sphere suspended in a magnetic field from a torsion fiber give the expected results as a function of the magnetic field and the conductivity as long as the Sn is a normal conductor. Below the transition temperature, however, the damping torque becomes less than  $10^{-5}$  times its value in the normal state and no changes in period are observed except those attributable to residual frozen-in moments. (*PA*, v. 54, #327)

### 337. INVESTIGATION OF SUPERCONDUCTIVITY IN LEAD COMPOUNDS

Hudson, R. P.

*Proceedings of the Physical Society, London*, v. 64A, pp. 751-752, 1951

Ingots prepd. by fusion and pptd. powder both finely

divided and sintered were measured. In most cases no transition could be observed down to 1.3°K., and the X-ray photographs contained only PbS lines. In a few specimens a very small (partial vol.) effect was found at 7.3°K., the normal Pb transition temp., and the X-ray patterns for these specimens included a very weak extra line presumably due to excess Pb. Crystals of galena and of pure com. PbS also gave neg. results. A fused sample of PbTe became supercond. at 7.3°K., the magnitude of the effect indicating that it was confined to a small fraction of the total vol. of the specimen, and the presence of Pb was confirmed by X-ray. (*CA*, v. 46, 9920a)

### 338. SUPERCONDUCTIVITY OF PURE METALLIC RHENIUM

Hulm, J. K.

Letter in *Physical Review*, v. 94, pp. 1390-1391, June 1, 1954

A rod prepared by melting pure compressed powder showed nearly "ideal" superconducting behavior, with a critical view given by  $H_c = 188 [1 - (T/1.699)^2]$ . A possible explanation for the much smeared out transition at rather higher temperatures previously found for powdered metal is discussed. (*PA*, v. 57, #9262)

### 339. INTERFERENCE IN COMPLEX LIGHT WITH LARGE PATH DIFFERENCES

Hunzinger, J. J.

*Revue d'optique*, v. 33, pp. 257-265, June 1954 (in French)

Derivation of formulae for multiple-beam interference taking into account the complexity of spectral-radiation and line width. Fringe contrast is evaluated. The theory is applied to visibility effects for two wavelengths. The influence of a Gaussian distribution in the line source is discussed in detail. (*PA*, v. 57, #11081)

### 340. ON THE ENTROPY OF THE SUPERCONDUCTOR

Itimura, H.

*Journal of the Physical Society of Japan*, v. 2, pp. 184-187, November-December 1947

This is calculated for zero magnetic field using a simple model with the properties: (1) the metal contains  $N$  conduction electrons per unit volume forming a degenerate Fermi gas; (2) below the transition temperature the "condensed" part consists of  $p$  groups of electrons per unit volume each containing  $\gamma$  electrons; (3) on each of

these condensed electrons there operates an attractive potential  $\phi' < \phi s(1 - \nu^*)$  where  $s = p/pT = 0$  and  $\phi$  and  $\nu$  are adjustable constants; (4) in the counting of the number of states each condensed group is considered as a whole; and (5) the ground level of the condensed phase is higher in energy than the Fermi surface by a quantity  $\delta$ . Although this model cannot explain the sharp kink in the experimental entropy-temperature curves, their general shape is reproduced if the fraction of electrons condensed at absolute zero is  $\sim 6.6 \times 10^3$  electrons and  $\phi$  and  $\delta$  are the order of a Bohr magneton. (PA, v. 53, #4097)

**341. ON THE QUESTION OF SUPERCONDUCTIVITY OF DISTURBANCE-CENTER SEMICONDUCTORS (PbS)**

Justi, E., Schultz, H.

*Zeitschrift für Naturforschung*, v. 8a, pp. 149-155, February-March 1953 (in German)

Evaporated layers of PbS with excess S or a small excess of Pb do not become superconducting, but show, with falling temperature, an increase in resistance towards infinity. With a larger excess of Pb, however, one always observes superconductivity. This begins with a steep decrease in resistance at the transition point of Pb which is ascribed to small depositions of the metal. After this follows a more or less extended temp. region in which the remaining resistance gradually disappears. In this region the resistance is independent of the measuring current. This indicates that the current is not carried by continuous threads of metallic lead but goes through the PbS proper, which has a concentration of carrier electrons of  $10^{20}$  to  $10^{21} \text{ cm}^{-3}$ . Another explanation would be that the PbS forms contact layers between the Pb grains, as it is known that contacts involving a considerable thickness of insulating oxide can become superconducting (Holm and Meissner, *Zeitschrift für Physik*, v. 74, p. 715, 1932). (PA, v. 56, #4814)

**342. NO SUPERCONDUCTIVITY IN Na-NH<sub>3</sub> SOLUTIONS**

Justi, E., Vieweg, G.

*Naturwissenschaften*, v. 36, no. 11, pp. 243-244, 1949 (in German)

Confirmation of earlier results by various authors (PA #3156, 1946; #878, #1212, #1866, #2941, #3201, 1947; #122, 1948). The specimens were in the tubes of 2mm diameter. The resistance measurements were carried out

with a potentiometer using low measuring currents, the Earth's magnetic field being compensated. The lowest resistivity found was  $5 \times 10^{-4} \Omega \text{ cm}$  at  $90^\circ$  with a solution of 0.95 molar Na concentration. No persistent currents nor Meissner effect could be detected in induction measurements employing magnetic fields of 2 oersted. (PA, v. 53, #4094)

**343. EXPERIMENTS AT EXTREMELY LOW TEMPERATURES**

Kanda, E.

*Kagaku*, v. 25, pp. 59-67, 1955

Kanda describes the production of low temps. down to  $0.002^\circ \text{K}$ . and the measurements, at any temp. higher than that of supercond., magnetic properties, nuclear magnetic resonance absorption, paramagnetic resonance, properties of liquid He II, elec. and magnetic properties of semiconductors, etc., as developed at the Insti. of the Study of Metallic Materials of Tohoku Univ. Possibilities of nuclear alignment are discussed. (CA, v. 49, 5904b)

**344. THE SURFACE RESISTANCE OF SUPERCONDUCTING TIN AT A FREQUENCY OF 9400 MEGACYCLES**

Khaikin, M. S.

*Doklady Akademii Nauk*, SSSR, v. 86, pp. 517-520, 1952; cf. CA, v. 46, 3881h

The surface resistance of superconducting Sn was calcd. from the properties of a resonator made up of the material being tested. The normal cond. and the dielec. const. were calcd. In these expt. a new phenomenon was observed, i.e., the polarization of the metal increases significantly in its transition from the normal to the superconducting state. (CA, v. 49, 14400i)

**345. EFFECT OF PLASTIC DEFORMATION ON THE SUPERCONDUCTIVITY OF METALS**

Khotkevich, V. I., Golik, V. R.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 20, pp. 427-437, 1950

(1) The wires were deformed by compression, and the ratio  $r = R'_0/R_0$  of the residual elec. resistances of the deformed and the original sample at  $4.2^\circ \text{K}$  was taken as criterion of the degree of plastic deformation, expts. with Sn wires of 0.19, 0.135, 0.10, and 0.08 mm. diam. having shown that  $r$  increases regularly with the load applied,

faster with thinner wires, and reaches a satn. level with sufficiently high loads. With Sn, deformation shifts the curves of the elec. resistance  $R$  as function of abs. temp.  $T$  to lower  $R$  at the same  $T$ ., the lower the greater the load applied (0, 140, 200, and 250 kg. on a wire of 0.135 mm. diam.); increase the plastic deformation thus results on increasing growth of the residual resistance accompanied by increasing broadening of the range of superconductive transition. Plots of the "conventional" reduced resistance  $R_c$  (= ratio of  $R$  at the given deformation and temp.  $T$  and  $R$  of the same sample at 4.2°K) as a function of  $T$ , for different  $r$ , show that the crit. temp. of superconductive transition  $T_c$  first rises with increasing  $r$  up to  $r \sim 7$  where it reaches a max. and then falls with further increasing  $r$ , tending to the  $T_c$  of the undeformed sample;  $T_c$  remains defined, as usual, as the temp. at which  $R_c = 0.5$ , but actually the deformed samples begin to show superconductive properties at markedly higher temps. The height of the max.  $T_c$  as a function of  $r$  decreases with the diam. of the wire, but its position remains invariable. When the load corresponding to max.  $T_c$  is removed, the transition curve, instead of reverting to its original position, continues to move farther to higher temps., so that  $T_c$  becomes 0.35-0.40° higher than originally. The behavior of In is entirely analogous to that of Sn. In the case of Tl, plastic deformation results in an uninterrupted rise of  $T_c$ , reaching satn. only at very high loads, and showing only a very slight fall beyond the satn. Removal of the load again results in a further rise of  $T_c$ . The behavior of Hg is altogether different from that of Sn, In, or Tl, with  $T_c$  moving linearly to lower temps. with increasing load, and removal of the load resulting in a practically complete return of the transition curve to its original position, close to the curve of undeformed Hg. (2) For Sn, In, and Hg, the temp. coeff. of the crit. magnetic field  $dH_c/dT$  increases only very slightly with the deformation, but Tl shows a strong increase, up to 500 gauss/deg, as compared with 150 for the original Tl. At the same time, the width of the transition range increases markedly (particularly with Tl) attaining several tens of gauss. (3) The above effects are observed only if the plastic deformation is effected at low temp.; heating up to room temp. results in complete disappearance of all the anomalies. Compression at 77°K does produce the anomalies but about 0.1 as large as in deformation at 4.2°K. Compression at room temp. produces no anomaly whatsoever, not even in Ta. (4) Plots of the relative shift  $\Delta T_c/T_c$  as a function of  $r$  show monotonous increase for Tl, a max. for In and Sn, and monotonous decrease for Hg. The latter shows a behavior

analogous to that under all-sided compression. In contrast thereto, all-sided compression of Tl is known to raise  $T$ , and that is observed also in plastic deformation; on the other hand, removal of the load restores the original situation after all-sided compression, whereas, under the same condition  $T_c$  continues to rise after plastic deformation. With Sn and In, all-sided compression always lowers  $T_c$ , whereas, plastic deformation gives a max. (5) The behavior of Sn, In, and Tl can be explained on the assumption that plastic deformation produces a new state, characterized by a higher  $T_c$ ; the normal effect of all-sided compression which lowers  $T_c$  is superposed on that change of state. For Tl, it must be assumed that plastically deformed Tl has a normal sign of  $dT_c/dP$ , and this is confirmed for  $r > 12$ . It is possible that under the conditions of these expts. Tl has undergone the polymorphous transition Tl II  $\rightarrow$  Tl III (see Bridham, CA, v. 30, 915<sup>s</sup>, 3705<sup>4</sup>). An indication that these processes are not merely the result of an accumulation of phys. defects is seen in the fact that the width of the range of the superconductive transition, which, as a function of  $r$ , passes through a max. for Sn, increases linearly in the case of Hg. (CA, v. 45, 8836i)

#### 346. MEASUREMENT OF THE DEPTH OF PENETRATION OF A MAGNETIC FIELD INTO MERCURY FILMS

Khukhareva, I. S.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 33, no. 7(1), pp. 301-303, 1957 (in Russian)

The paper summarizes very briefly the various methods of preparation of thin mercury films and determination of their thickness by weighing. Results are given of measurements of the variation of resistance of a film with temperature and also of determinations at various temperatures of the curves of transition from superconducting to normal state, with increase of magnetic field applied parallel to the plane of the film. The Ginzberg-Laudau formula is used to calculate the penetration depth and the results are used to derive an apparently very satisfactory temperature-depth of penetration relationship. (PA, v. 61, #3148)

#### 347. THE SUPERCONDUCTIVITY OF THIN FILMS OF TANTALUM AND NIOBIUM

Khukhareva, I., Shal'nikov, A.

*Doklady Akademii Nauk, SSSR*, v. 99, pp. 735-736, 1954

Films of Nb and Ta were prepd. by cathode sputtering in a Ne atm. and by evapn. onto a glass surface in a vacuum. The superconducting properties of these films were studied. As the film thickness increases the crit. temp. is shifted toward higher temps. (CA, v. 49, 12894d)

#### 348. SUPERCONDUCTIVITY OF URANIUM

Kilpatrick, J. E., Hammel, E. F., Jr., Mapother, D.  
*Physical Review*, v. 97, pp. 1634-1635, 1955

U has a broad (0.2-0.3° wide) transition, which is centered at 0.77-0.80°K for 3 samples of U. (CA, v. 49, 8643g)

#### 349. ON THE DESTRUCTION OF SUPERCONDUCTIVITY BY LARGE CURRENTS

Kuper, C. G.  
*Philosophical Magazine*, v. 43, pp. 1264-1275, December 1952

A theoretical study is made of the restoration of resistance in superconducting wires by large currents. The experiments of Shubnikov and Alexeevsky and of Scott show a marked deviation from the theory of F. London. The present theory uses the same geometrical model of the structure as London; i.e., a string of superconducting conical domains along the axis of the wire. But it takes account of the effect on the resistance of the scattering of electrons at successive normal superconducting interfaces, when their separation is comparable to the mean free path of the electrons in the normal phase. The scale of the structure is determined by minimizing the "Magnetic Gibbs' Function." It is shown that the interfacial surface energy may be neglected. The theory is in fair agreement with the rather scanty experimental data. The only parameter of the theory is the mean free path of electrons, and the value assigned is consistent with that obtained from other phenomena. (PA, v. 56, #1645)

#### 350. SOME EXPERIMENTS ON SUPERCONDUCTIVITY AT RADIO-FREQUENCIES

Lazarev, B. G., Galkin, A. A., Khotkevich, V. I.  
*Comptes Rendus de l'Académie des Sciences de l'URSS*, v. 55, no. 9, pp. 805-807, 1947

Alternating currents of either 50 or  $2.3 \times 10^6$  to  $2 \times 10^7$  c/s were superimposed on a direct current in wires of superconducting Tl. A dc voltage was observed which went through a max. if the ac was increased at const. dc.

At 50 c/s the results can be understood by assuming instantaneous destruction and re-establishment of superconductivity when the critical field is passed. At rf the max. becomes more and more flattened as the frequency increases. This behaviour is thought to be due to relaxation phenomena with a time constant of  $\sim 10^{-8}$  sec. (PA, v. 51, #125)

#### 351. SOME PECULIARITIES OF THE SUPERCONDUCTIVITY OF TANTALUM

Lazarev, B. G., Khotkevich, V. I.  
*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, USSR, v. 18, pp. 807-811, September 1948

Preliminary investigations into the superconductivity of Ta revealed the high sensitivity of the phenomenon to various lattice deformations. The anomalies of the superconductivity of Ta were considered as representative of the group of "heavy" superconductors. (PA, v. 53, #579)

#### 352. VOLUME CHANGE OF TIN IN THE SUPERCONDUCTIVE TRANSITION IN THE MAGNETIC FIELD

Lazarev, B. G., Sudovtsov, A. I.  
*Doklady Akademii Nauk, SSSR*, v. 69, pp. 345-347, 1949

The relative volume increase  $\Delta v/v$  was detd. from the deflection in the magnetic field of a bimetallic ribbon wound in a spiral, with Sn outside and brass inside the spiral; high sensitivity, and an accuracy of 10%, was obtained owing to great length, 4 m., of the ribbon. The data,  $T = 3.723, 3.0, 2.0, 1.4^\circ\text{K}$ ,  $10^8 \Delta v/v = 0, 6.05, 8.89, 1.4$ , agree with the thermodynamic calcn. from the pressure dependence of the crit. magnetic field. They contradict Heisenberg's theory ascribing the vol. change to magnetostriction, which can account only for 2% of the observed effect. Possible contamination of the Sn by brass is not apt to be significant owing to the thickness ( $\sim 1$  mm) of the Sn layer. (CA, v. 44, 2300A)

#### 353. SUPERCONDUCTIVITY IN A DENDRITIC DEPOSITION OF PURE TIN

Leinhardt, T. E., Reynolds, J. M.  
*Physical Review*, v. 87, p. 198

(CA, v. 48, 4973f)

### 354. SEARCH FOR THE HALL EFFECT IN A SUPERCONDUCTOR. I. EXPERIMENT

Lewis, H. W.

*Physical Review*, v. 92, pp. 1149–1151, December 1, 1953

A search has been made for a Hall effect in superconducting vanadium, using a new method that avoids some of the difficulties previously encountered. The result is negative, with an upper limit of  $150 \times 10^{-6}$  e.m.u., which can be compared with the value of  $800 \times 10^{-6}$  e.m.u. for normal vanadium. The theoretical implications will be discussed in a separate paper. (PA, v. 57, #2445)

### 355. KINETICS OF DESTRUCTION OF SUPERCONDUCTIVITY BY A HIGH-FREQUENCY FIELD

Lifshits, I. M.

*Doklady Akademii Nauk, SSSR*, v. 90, no. 4, pp. 529–531, 1953 (in Russian)

The theory of the following abstract is extended to apply to frequencies up to  $10^4$  Mc/s where mean-free-path effects are important and the conditions of the anomalous skin effect apply. (PA, v. 57, #3499)

### 356. KINETICS OF DESTRUCTION OF SUPERCONDUCTIVITY BY AN ALTERNATING FIELD ( $\omega \leq \sim 10^{-6} \text{ sec}^{-1}$ )

Lifshits, I. M., Kaganov, M. I.

*Doklady Akademii Nauk, SSSR*, v. 90, no. 3, pp. 363–366, 1953 (in Russian) English translation, US National Science Foundation, NSF-tr-114

In experiments by Lazarev and Galkin and others a steady magnetic field and an alternating one are superimposed on a superconductor so that during part of each period the field exceeds the critical value; destruction of superconductivity takes place by the movement into the metal of a boundary between superconducting and normal phases. The kinetics of this process is discussed, taking into account both the possibility of relaxation effects and of superheating. The discussion is limited to frequencies  $< 1$  Mc/s, so that mean-free-path effects are unimportant, and expressions are given for the depth of the boundary as a function of time for various limiting conditions. (PA, v. 57, #3498)

### 357. SUPERCONDUCTIVITY OF TIN ISOTOPES

Lock, J. M., Pippard, A. B., Shoenberg, D.

*Proceedings, NBS Semicentennial Symposium on Low-Temperature Physics*, National Bureau of Standards, v. 519, pp. 31–32, 1952

The transition temps and crit. magnetic fields were detd. by S's ballistic method for isotopes of Sn, sepd. electromagnetically, whose mean at. wts. were  $116.2 \pm 0.05$ ,  $119.9 \pm 0.05$ , and  $123.75 \pm 0.1$ . The test specimens were thin wires cast in  $\text{SiO}_2$  capillaries. The particularly sharp transitions observed for  $\text{Sn}^{116}$  and  $\text{Sn}^{124}$  gave the difference in their transition temps. as  $\Delta T_c = 0.108 \pm 0.001^\circ\text{K}$ . The transition temps. are  $\text{Sn}^{116}$ ,  $3.767^\circ\text{K}$ ;  $\text{Sn}^{120}$ ,  $3.712^\circ\text{K}$ ; and  $\text{Sn}^{124}$ ,  $3.659^\circ\text{K}$ , but these may be subject to slight corrections for the hydrostatic head of liquid He. This possible error does not affect  $\Delta T_c$ .  $\text{Sn}^{116}$  and  $\text{Sn}^{124}$  also showed sharp magnetic transitions, and  $\Delta H_c$  was measured at a no. of temps. down to  $1^\circ\text{K}$  with an accuracy of 0.05 gauss. For  $\text{Sn}^{116}$ ,  $H_0 = 307.5$  gauss with  $\Delta H_0 = 8.90 \pm 0.05$  gauss. The data are interpreted as verifying the assumption that  $H_0/T_c$  is const. for the different isotopes. This implies that the electronic sp. heat of Sn is independent of the isotopic mass. The results confirm the theoretical predictions of Fröhlich and of Bardeen. (CA, v. 47, 8432c)

### 358. SUPERCONDUCTING TRANSITIONS IN TIN WHISKERS

Lutes, O. S., Maxwell, E.

Letter in *Physical Review*, v. 97, no. 6, pp. 1718–1720, March 15, 1955

The restoration of resistance by a transverse field in very thin short tin wires ("whiskers,"  $1.2 \times 10^{-4}$  cm dia.  $50 \times 10^{-4}$  cm long) is much sharper than for the thicker wires studied by Andrew (Abstract 281). It is suggested that for such thin wires the intermediate state may not occur at all. (PA, v. 58, #4682)

### 359. EXPERIMENTS ON THE SUPERCONDUCTIVE TRANSITION

MacDonald, D. K. C., Mendelssohn, K.

*Proceedings of the Royal Society of London, Series A*, v. 200, pp. 68–84, December 22, 1949

The change of electrical resistivity at the transition between the superconductive and the normal state in a longitudinal magnetic field has been investigated sys-

tematically. By successive elimination of a number of disturbing factors an experimental procedure has been developed which yields consistent and reproducible results. The metals Pb, Hg, and Sn have been investigated in this manner. Contrary to the accepted view it has been found that under "ideal" conditions that transition is not discontinuous. There exists a range of temp. and mag. field in which the resistance changes from normal to zero and vice versa. The extent of this transition region was found to grow rapidly with increasing absolute value of the mag. field. Under conditions closely approximating the "ideal" longitudinal case, transitions with hysteresis were never observed. However, it could be shown that resistance hysteresis and discontinuous resistive changes are produced by deviation from the longitudinal case owing to unsuitable geometrical shape of the specimen. The general conclusion has been reached, therefore, that the resistance of a pure superconductor in a longitudinal field changes continuously in transition between the superconductive and the normal state. The significance of the results has been discussed and further experiments have been proposed. (PA, v. 53, #2468)

### 360. THE SUPERCONDUCTIVE TRANSITION

MacDonald, D. K. C., Mendelssohn, K.

Letter in *Nature*, v. 162, p. 924, December 11, 1948

The restoration of resistance of superconducting pure Sn, Hg and Pb by longitudinal magnetic fields even for good specimens was found to be spread over a short range of fields  $\propto$  the critical field at that temperature. No hysteresis effects were observed except with specimens which ended in bulbs. (PA, v. 52, #3995)

### 361. ON THE INTERACTIONS IN A FERMI GAS. POLARIZATION PHENOMENA, CORRELATION ENERGY, ELECTRON CONDENSATION

Macke, W.

*Zeitschrift für Naturforschung*, v. 5a, pp. 192-208, April 1950 (in German)

The properties of electrons moving in a region of constant positive charge density are investigated "wave-mechanically." An estimate is made of the correlation energy between electrons by using a perturbation method, in which the Coulomb interaction between the electrons is the perturbing term, and summing all correction terms for the energy of the electron gas. The expression is similar to the result one obtains on determining the energy

by a variational method and using screened Coulomb potentials  $er_{ij}^{-1} \exp(-\lambda r_{ij})$  as the perturbing term. This result is interpreted as establishing an analogy between the correlation energy in an electron gas and the polarization energy in Debye's theory of electrolytes. In both cases it is supposed that a screening of the repulsive forces is effected due to the polarization by the current carriers of their surroundings. This result is discussed in relation to the phenomenon of electron condensation at the surface of the Fermi sphere as suggested in Heisenberg's theory of superconductivity (PA, #3203, 1947). It is concluded that Heisenberg's assumptions are justified; i.e., that the electrons at the surface of the Fermi sphere have exceptional properties, and that their mutual interactions establish a long-range order between them. (PA, v. 53, #7025)

### 362. TWO FLUID MODELS OF SUPERCONDUCTIVITY WITH APPLICATION TO ISOTOPE EFFECTS

Marcus, P. M.

National Bureau of Standards, 1952

A general form of the two-fluid model of a superconductor, which includes all previous forms, is set up and the underlying assumptions examined in the light of the lattice-vibration theory of superconductivity. Thermodynamic relations are derived and their consistency with the observed isotope effects indicated. Specialization to the  $\alpha$ -model of Casimir and Gorter permits fitting recent precise critical-field data and evaluation of the parameter  $\alpha$  characterizing different superconductors. Comparison is made with Kopp's form of the two-fluid model, which is shown not to fit all the data, and simplified and limiting forms of his equations are given. (NSA, v. 7, #4152)

### 363. SUPERCONDUCTING COMPOUNDS OF NONSUPERCONDUCTING ELEMENTS

Matthias, B. T.

*Physical Review*, v. 90, p. 487, 1953

The compds., and the temp. ( $^{\circ}\text{K}$ ) at which they become superconducting, are: (NiAs) structure: PdSb,  $\sim 1.5$ ; PtSb,  $\sim 2.1$ , PtBi,  $\sim 1.21$ ; PdTe,  $\sim 2.3$ ; (MnP) structure: IrGe,  $\sim 4.7$ . (CA, v. 47, 9076g)

### 364. SUPERCONDUCTIVITY IN THE COBALT-SILICON SYSTEM

Matthias, B. T.

*Physical Review*, v. 87, p. 380, 1952

A Co-Si melt with 75 at. % Si becomes superconducting at 1.33°K. There are two phases, Si and CoSi<sub>2</sub>, in roughly equal proportions. The CoSi<sub>2</sub> is the superconducting phase. Annealing this melt lowered the transition temperature. (CA, v. 46, 9400g<sup>2</sup>)

### 365. SUPERCONDUCTING COMPOUNDS

Matthias, B. T., Corenzwit, E., Miller, C. E.

*Physical Review*, v. 93, p. 1415, 1954

(CA, v. 46, 19751i, v. 48, 1745f)

The hypothesis previously advanced was used to discover addnl. superconducting compds. and mixts. They are: Mo<sub>2</sub>P, ~7°K; Rh<sub>5</sub>P<sub>4</sub>, 1.22°K; the solid solns. Ni<sub>0.75</sub>->0.12 Pd<sub>0.25</sub>->0.88 As, >1.06°K; Ni<sub>0.25</sub> Pd<sub>0.75</sub> As, 1.6°K; Rh<sub>9</sub>S<sub>8</sub>, 5.8°K; 2Rh: 3.4-4Se, >1.04°K; 2Rh: 3.5Se, ~6°K; 2Rh: 4Te, 1.51°K. Compds. that did not become superconducting at ~1.03°K were MoP, Rh<sub>2</sub>P, Rh<sub>2</sub>Se<sub>5</sub>; at 1.28°K, NiAs. (CA, v. 48, 7358a)

### 366. SUPERCONDUCTIVITY OF Nb<sub>3</sub>Sn

Matthias, B. T., Geballe, T. H., Geller, S., Corenzwit, E.

*Physical Review*, v. 95, p. 1435, 1954

Nb<sub>3</sub>Sn and Ta<sub>3</sub>Sn were prep'd. by having molten Sn run over Nb or Te powder in a sealed quartz tube at 1200°. Ta<sub>3</sub>Sn becomes superconducting near 6°K. Nb<sub>3</sub>Sn becomes superconducting at 18.05 ± 0.1°K. This is the highest transition temperature known. (CA, v. 48, 13298f)

### 367. NEW SUPERCONDUCTING COMPOUNDS

Matthias, B. T., Hulm, J. K.

*Proceedings of NBS Semicentennial Symposium on Low-Temperature Physics*, National Bureau of Standards, v. 519, p. 69, 1952

Specimens of SrBi<sub>3</sub> and BaBi<sub>3</sub>, both of which crystallize as silvery cubes, were prep'd. Measurements of their magnetic susceptibilities indicate that SrBi<sub>3</sub> becomes superconducting at about 5.5°K and BaBi<sub>3</sub> at a little above 6°K. Mo<sub>2</sub>B, Mo<sub>2</sub>N, and MoN are all superconducting, but above 1.3°K the other borides of Mo, as well as Mo<sub>2</sub>P, are not superconducting. The transition temp. of MoN is about 12°K. No exptl. details are given here but are published elsewhere (see CA, v. 45, 5478b). (CA, v. 47, 7845c)

### 368. SUPERCONDUCTING PROPERTIES OF COBALT DISILICIDE

Matthias, B. T., Hulm, J. K.

*Physical Review*, v. 89, pp. 439-441, 1953

A solid rod of CoSi<sub>2</sub> had a superconducting transition temperature close to 1.4°K, a crit. field gradient of 146 gauss per deg at the transition point, and ice-point resistivity of 16.5 μohm cm, and a residual resistivity of about 16% of the ice-point value. (CA, v. 47, 6725d)

### 369. SUPERCONDUCTIVITY OF THE ISOTOPES OF TIN

Maxwell, E.

*Physical Review*, v. 86, pp. 235-242, 1952

The superconducting transition temps. of 6 samples of Sn with at. masses of 113.58-123.01 obey the relation  $M^{0.505}T_c = \text{const.}$  The critical field curves for samples of at. mass 113.58, 118.05, and 123.01 were similar to 1 part in 800, 1.4-3.8°K. This shows that the electronic sp. heat in the normal state is independent of at. mass, and that the thermodynamic functions derived from the crit. field curves also have the similarity property. (CA, v. 46, 5912f)

### 370. THRESHOLD FIELD PROPERTIES OF SOME SUPERCONDUCTORS

Maxwell, E., Lutes, O. S.

*Physical Review*, v. 95, pp. 333-338, July 15, 1954

Some refined measurements of the critical field curves for tin, thallium, indium, and mercury have been completed and the results compared with the specific predictions of the Gorter-Casimir and the Koppe versions of the two-fluid model of superconductivity. Neither version is completely adequate, although each has points in its favor. The Koppe prediction of a universal critical field curve for all superconductors is not verified. The Gorter-Casimir α-model has greater flexibility than the Koppe model, and although it is capable of giving a fair description of the critical field data, it is in some respects also inconsistent with the data. The isotope effect in thallium has been observed and is consistent with the half-power law. (PA, v. 57, #9264)

### 371. MEASUREMENTS IN THE TRANSITION REGION TO SUPERCONDUCTIVITY III.

Meissner, W., Schmeissner, F., Meissner, H.  
*Zeitschrift für Physik*, v. 132, no. 5, pp. 529-543,  
 1952 (in German)

For Part II, see Abstract 230 (which requires correction, as follows: penultimate line, for  $j$  read  $\gamma$ ; last line, add "if  $H$  is measured in amp/cm"). Rod-shaped Sn and Hg specimens were used, which show in the transition region an increase of the flux produced by a longitudinal magnetic field above its value in the normal state if an electric current passes through the rod. The time variation of the flux on switching on and off or commutating the magnetic field is studied. Further experiments concern hollow cylinders of Hg. These show an increase of flux also in the cavity as long as the specimen is in the transition range. When the specimen has reached the superconducting state by cooling, the final flux in the cavity is again normal. These experiments prove that the increased flux is due to a macroscopic circular current and not to a volume magnetization. Slotted hollow cylinders show no super-normal flux, not even in body of the specimen. The same is true for a slotted solid cylinder. Comparison of the slotted and nonslotted specimens show that the maximum flux in the latter occurs when, with falling temperature, the already formed superconducting regions begin to grow together. After this the whole specimen becomes superconducting within a very small temperature interval. Finally some not very pure Ta-rods have been investigated. With these the increase in flux was only  $\frac{1}{10}$  of that found in Hg. (PA, v. 56, #1646)

### 372. ADIABATIC MAGNETIZATION OF SUPERCONDUCTORS

Mendelssohn, K.  
*Nature*, v. 169, p. 366, March 1, 1952

The magneto-caloric effect in superconductors may be used as a supplement to the paramagnetic method in obtaining and studying temperatures below  $1^\circ\text{K}$ . An expression for the degree of cooling obtained is derived. Use of metals with high transition and Debye temperature, such as Ta and Nb, permits temperatures below  $0.1^\circ\text{K}$  to be reached. The method is particularly valuable in the region of  $0.3$  to  $1^\circ\text{K}$ . (NSA, v. 6, #2681)

### 373. STRUCTURE OF A SUPERCONDUCTOR IN THE TRANSITION STATE

Meshkovskii, A.  
*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*,  
 v. 19, pp. 54-62, 1949; cf. CA, v. 44, 2809 g

Two dimensional maps of the normal ( $N$ ) and the superconducting ( $S$ ) areas in a single-crystal sphere of 99.96% pure Sn were obtained by evaluation of explorations made by the detn. of the elec. resistance of a fine Bi wire moved in 2 directions along a series of chords of the equatorial section in the slit between 2 hemispheres of 19.7 mm radius, distant by 0.2 mm. Explorations at  $3^\circ\text{K}$  in a field of 70 oersteds, with the  $S \rightarrow N$  transition brought about at const. temp. through increase of the magnetic field, or at  $2.85^\circ\text{K}$  and 81 oersteds, with the  $N \rightarrow S$  transition produced by lowering the temp. at const. magnetic field, yielded substantially the same distribution picture, namely, an essentially irregular distribution of areas of the  $N$  phase over the equatorial section, but with a distinct tendency to radial arrangement along the periphery. On the basis of these results, the whole of the equatorial region of a continuous sphere would be occupied by a belt of the  $N$  phase growing in radially directed layers oriented along meridian sections, spreading north and south of the equatorial plane so as to hit the surface of the 2 hemispheres. Nearer the center of the sphere, the  $N$  areas seem to have the shape of isolated fibers and bent plates. The proportions of the  $N$  phase, read from the exptl. maps, are, however, much greater than the values required by the conservation of magnetic flux. The root of the discrepancy is that areas appearing to be pure  $N$  are actually intimately mixed with  $S$  which forms numerous inclusions within the  $N$  phase. (CA, v. 44, 6223f)

### 374. THE STRUCTURE OF SUPERCONDUCTORS IN THE TRANSITION STATE II.

Meshkovskii, A. G., Shal'nikov, A. I.  
*Izvestiya Akademii Nauk SSSR, Seriya Fizicheskaya*,  
 v. 11, pp. 39-75, 1947; *Chemisches Zentralblatt*  
 (Russian Zone Edition), 1948, II, pp. 1157-1158

The distribution of superconducting layers in the transition state is investigated by measuring in a magnetic field with improved devices the field distribution in superconducting 20- and 39-mm-diam. single-crystal spheres of Sn and 28-mm-diam. polycryst. spheres of Sn. The Bi ribbons ( $5 \times 10 \times 300\mu$ ) are movable along the diam. of

the sphere and the fluctuations of the resistance are recorded with a sensitive galvanometer on photographic paper placed on a synchronized drum. This device allows the registration of complete field distributions within 5 min. In the superconducting state the field = 0; in the transition state (approaching the normal state) increasingly irregular curves are obtained for the field distribution corresponding to the formation of superconducting and normal layers. In the normal state the field is again homogenous. Reaching a certain transition state by a change of  $T$  at  $H = \text{const.}$  results in a more regular field distribution than reaching it by a change of  $H$  at  $T = \text{const.}$  The previously reported crit. slit width with larger Bi ribbons is not observed here. A nonhomogenous field distribution occurs in the immediate vicinity of the hemisphere with a slit of 2.3 mm. The lines of force are almost completely homogenous in the center of the slit. Quant. comparisons with the theory of Landau are not possible because of the irregularity of the layers. (CA, v. 45, 9328i)

**375. INFLUENCE OF PRESSURE ON THE RESISTANCE OF GOLDSILVER ALLOYS**

Michels, A., Wassenaar, T.

*Physica*, v. 14, pp. 61-62, April 1948 (in English)

The electrical resistance was measured as a function of pressure, up to 2800 atmos. at 25 and 60°C. Pressure coefficients were calculated between 1 and 2600 atmos. Residual resistances at -78°C, -183°C and -196°C were also measured. Results obtained by extrapolating to -273.15°C are given. (PA, v. 51, #2475)

**376. EXPERIMENTAL AND THEORETICAL INVESTIGATION OF THE TRANSITION SUPERCONDUCTIVITY-NORMAL CONDUCTIVITY AND VICE VERSA AS A FUNCTION OF TIME FOR A HOLLOW CYLINDER WITH A CIRCULAR MAGNETIC FIELD**

Nabauer, M.

*Zeitschrift für Physik*, v. 152, pp. 328-367, 1958

(See Abstract 423) A timely resolution of the transition to the superconducting state of a single-crystal lead cylinder at 4.2°K was obtained by oscillographic recording of the change in magnetic flux with time  $d\phi/dt$ . It is concluded that the transition is effected by migration of a phase boundary in the cylinder, sepg. the 2 phases. (CA, v. 50, 19479f)

**377. CHANGE OF ELASTIC CONSTANTS IN A SUPERCONDUCTOR**

Olsen, J. L.

*Nature*, v. 175, p. 37, 1955

In order to measure the small difference between the elastic constns. of a superconductor in the superconducting and the normal states, a static method was used to measure the change in modulus of rigidity of a chemically pure polycryst. Sn wire (I) when superconductivity was destroyed by a longitudinal magnetic field. I was placed vertically in liquid He, fixed at the lower end, and connected at the upper end by a rigid rod to a P-bronze wire (II) held at room temp. A twist applied to II distributed itself between I and II according to their torsional constns. When the superconductivity of I was destroyed, the change of the equil. distribution of strain was observed by means of an optical lever. Too much torsion of I caused excessive creep so that the deflections measured were less than  $5 \times 10^{-7}$  radians. The results of several runs were plotted as  $(G_n - G_s)/G_n$  vs  $T^\circ\text{K}$ , where  $G_n$  and  $G_s$  are the rigidities for the normal and superconducting states, resp. Results for uncalibrated runs were normalized to fit the calibrated runs at 2°K. The full curve was represented by the function  $A[1 - (T/T_c)^4]$ , where  $T_c$  is the transition temp and the const.  $A$  was chosen for agreement with the observations at 2°K. (CA, v. 49, 10687h)

**378. THE BOSE-EINSTEIN CONDENSATION FOR CHARGED PARTICLES IN A MAGNETIC FIELD**

Osborne, M. F. M.

*Physical Review*, v. 76, pp. 400-406, August 1, 1949

The condensation and accumulation phenomena of charged Bose-Einstein particles in a magnetic field are examined, neglecting electrostatic interactions. For weak fields a single condensation occurs at the same temp. as that for uncharged particles; for strong fields there is a separate lower accumulation temp., indicating the accumulation of particles in the lowest translational state. The total energy, free energy, and polarization are calculated, and applied to the properties of a gas of electron pairs, and a solution of deuterons in a metal, these being systems whose low temp. behavior might show a Bose-Einstein condensation. It is shown that the Bose-Einstein condensation of free electron pairs cannot provide a theory of superconductivity. (PA, v. 53, #942)

### 379. SUPERCONDUCTIVE TRANSITION IN LEAD Preston-Thomas, H.

*Canadian Journal of Physics*, v. 30, pp. 626-627, 1952

In 1949 MacDonald and Mendelssohn (see Abstract 359) noted discrepancies between the magnetic and resistive crit. fields for Pb when superconductive. This suggests that its behavior may in reality be similar to that of the "hard" superconductors Nb and Ta. To test this, P.-T. measured the magnetic and resistive transitions in spectroscopically pure Pb at 4.21°K and 3.28°K. The magnetic transition is approx. discontinuous. That is, from this point of view the Pb appears to be an ideal superconductor. The resistive transition, however, occurs over a considerable interval of magnetic field strength, and the extent of this range depends on the measuring current used and on the temp. The results are presented as two sets of graphs. One shows the transitions at 4.21°K, with the resistive transition observed for currents of 94, 10, and 2 ma.; the other gives the results at 3.28°K with currents of 94, 30, and 10 ma. These curves indicate that for sufficiently high c.d. the resistive transition agrees with the magnetic, as would be true for an ideal superconductor. The postulate of a discontinuous "filament" structure, suggested for Ta, can be used to explain this behavior of Pb. (CA, v. 47, 2001c)

### 380. THE SUPERCONDUCTIVE TRANSITION IN TANTALUM

Preston-Thomas, H.

*Physical Review*, v. 88, pp. 325-327, 1952

The construction of small coreless coils allows the simultaneous measurement of resistive and magnetic transitions in Ta. As in the case with the other "hard" superconductors, these measurements give the evidence of the presence of "filaments" in the metal. The results are explained on the basis of a modification of a 2-phase model used previously, and crit. field-temp. curves are derived for the bulk metal and for the filament material. (CA, v. 47, 936a)

### 381. MEASUREMENT OF THE SURFACE IMPEDANCE OF SUPERCONDUCTORS AT 9400 mc/s

Prozorova, L. A.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 34, no. 1, pp. 14-22, 1958 (in Russian)

The surface impedance of superconductors was measured at 9400 mc/s. The temperature dependence of the surface impedance of thin Sn and Hg films was investigated. The penetration depth for these films was determined and found to be in accord with critical magnetic field measurements. The effective conductivity of films in the superconducting state increases with decrease of the temperature. Dependence of the impedance of thin Sn and Hg films on the magnetic field strength was investigated at  $T < T_c$ . Dependence of the penetration depth on field strength agrees satisfactorily with the Landau-Ginsberg theory. (PA, v. 61, #7033)

### 382. GYROMAGNETIC EFFECT IN A SUPERCONDUCTOR

Pry, R. H., Lathrop, A. L., Houston, W. V.

*Physical Review*, v. 86, pp. 905-906, June 15, 1952

The gyromagnetic ratio of a superconducting tin sphere has been measured by the Einstein-DeHaas method. The result is approximately that to be expected on the picture of perfectly free superconducting electrons and is in agreement with the work of Kikoin and Gubar. (PA, v. 55, #6526)

### 383. THE EFFECT OF A MAGNETIC FIELD ON THE HEAT CONDUCTIVITY OF A SUPERCONDUCTOR

Renton, C. A.

*Philosophical Magazine*, v. 46, pp. 47-52, January 1955

A comparison is made between the heat conductivity data below 1°K in which the specimens were exposed to the magnetizing field and those observations in which the specimens were shielded. The thermal resistance of a tin single crystal in which superconductivity was destroyed by a transverse magnetic field has been examined in detail. The results are discussed and an explanation for the heat conductivity minimum in the intermediate state is suggested. (PA, v. 58, #1852)

### 384. SUPERCONDUCTIVITY OF ISOTOPES OF MERCURY AND TIN

Reynolds, C. A., Serin, B., Nesbitt, L. B.

*Proceedings, Semi-centennial Symposium on Low-Temperature Physics*, National Bureau of Standards, v. 519, pp. 27-28, 1952

The crit. magnetic fields,  $H$ , at temp.  $T$  were measured for several Hg isotopes down to 1.37°K. Over the whole temp. range  $H$  is a parabolic function of  $T$ . As shown by Kok this indicates that the difference in sp. heats per unit vol. between the normal and superconducting states has the form  $\gamma T + KT^3$ . The values of  $\gamma$ ,  $K$ , and  $H_0$  (the crit. field in oersteds, at abs. zero) were computed from the parabola corresponding to the isotope of av. mass no.  $M$ . Values for  $M$ ,  $H_0$ ,  $T_c$ ,  $\gamma$ ,  $K$ , and  $K/M$ , resp., are: 199.5, 420, 4.185°K, 1.600, 273, 1.37; 200.7, 419, 4.175, 1.600, 275, 1.37; 202.0, 417, 4.160, 1.600, 278, 1.375; 203.2, 414, 4.146, 1.590, 278, 1.37. Although  $\gamma$ , which depends on the electronic sp. heat in the normal state, is const.,  $K$  is proportional to  $M$ . Similar measurements made on 2 isotopes of S,  $M = 113.6$  and  $M = 123.8$ , and on 2 specimens of natural tin,  $M = 118.7$ , at 70 temps. between the crit. temp. and 1.27°K, gave parabolic  $H$ - $T$  curves below 2°K, although there was considerable deviation from this relation above it. The results for  $M$ ,  $T_c$ ,  $H_0$ , and  $H_0/T_d$  for Sn are resp.: 113.6, 3.805, 3.2, 82.0; 118.7, 3.732, 304, 81.5; 123.8, 3.659, 298, 81.4. The data for Sn confirm the constancy of  $\gamma$  for the different isotopes. The results confirm those given by Shoenberg. (CA, v. 47, 7846g)

### 385. SUPERCONDUCTING BISMUTH ALLOYS

Reynolds, J. M., Lane, C. T.

Letter in *Physical Review*, v. 79, pp. 405-406, July 15, 1950

The intermetallic compounds NaBi and KBi have transition temperatures of 2.24° and 3.6°K, transition ranges at zero field of 0.05° and 0.07° and initial slopes  $dH_c/dT$  of 180 and 130 gauss/°K respectively. There is an almost complete lack of hysteresis and the general behavior is that of a pure metal and not of an alloy. For the measurement Webber's ac induction method (Abstract 204) was used. The superconductivity of KBi<sub>2</sub> had so far not been reported; for NaBi see PA, v. 53, #978, 1950. (PA, v. 53, #8753)

### 386. DESTRUCTION OF SUPERCONDUCTIVITY IN THE FIELD DUE TO THE CURRENT CARRIED AND A TRANSVERSAL EXTERNAL FIELD

Rinderer, L.

*Zeitschrift für Naturforschung*, v. 10a, no. 2, pp. 174-175, 1955 (in German)

The results of resistance measurements with a tin wire at 3.5°K (critical magnetic field  $H_K = 29.8$  oersted) are shown as lines of equal resistance  $R/R_n$  in the  $H_I$ - $H_T$  plane,  $H_I$  being the magnetic field due to the current and  $H_T$  the value of an applied transversal field. The results are in qualitative agreement with the current view that in the transition region the wire divides into a normally conducting zone where  $H > H_K$  and a zone in the intermediate state in which the conductivity is  $>$  normal. For  $H_K \{1 + 2(H_T/H_K)^2/[2(H_T/H_K) + 1]\} < H_I$  the resistance is nearly independent of  $H_T$ , the field  $H_T$  merely shifting the central intermediate zone until it touches the surface of the wire. The normal limit of the intermediate state is extended by the current to values of  $H_T > H_K$  (theoretically to  $H_T = H_K + H_I$ , experimentally  $H_T \simeq H_K + \frac{2}{3}H_I$ ) owing to the opposing direction of  $H_I$  and  $H_T$  at one side of the wire. (PA, v. 58, #6154)

### 387. STRUCTURE OF THE INTERMEDIATE STATE IN SUPERCONDUCTORS

Schawlow, A. L.

*Physical Review*, v. 101, no. 2, pp. 573-579, January 15, 1956

A niobium powder method has been used to display the arrangement of normal and superconducting domains in the intermediate state of a superconductor. Patterns have been observed on samples of tin, indium, lead, vanadium and tantalum, and have been studied in some detail for tin. It has been found possible to produce patterns which are plane parallel lamina in a flat plate. From their spacing the surface energy at a superconducting-normal interface was evaluated. For tin, the surface-energy parameter,  $\Delta$ , is of the order of  $3 \times 10^{-5}$  cm. Both the magnitude of  $\Delta$  and its variation with temperature are consistent with theories of its origin advanced by Ginsburg and Landau, Bardeen and Lewis. Similar results were obtained for indium and lead, but hard superconductors like tantalum, and especially vanadium, give coarser patterns, indicating a very much larger surface energy. (PA, v. 59, #2125)

### 388. DESTRUCTION OF SUPERCONDUCTIVITY BY CURRENT

Scott, R. B.

*Journal of Research of the National Bureau of Standards*, Washington, D. C., v. 41, pp. 581-588, December 1948

A series of measurements was made of the return of resistance in superconducting wires when the current was increased up to and beyond the critical value. Wires of pure In of 3 different diameters were used, and measurements were made on each wire at 4 different temps. The transition curves for a wire of given diameter were reproducible and were independent of temp. Measurements on short wires 0.6 mm in length gave substantially the same results as measurements on long wires. The fraction of the normal resistance restored by the critical current varied from 0.77 for a wire 0.36 mm dia. to 0.85 for wires 0.11 mm dia. The classical formula predicts a value of 0.50. The results are discussed in the light of Landau's theory of the intermediate state, and it is shown that the classical value may be approached for wires of large diameter. (PA, v. 52, #4791)

### 389. STRUCTURE OF THE INTERMEDIATE STATE OF SUPERCONDUCTORS

Serin, B.

Letter in *Physical Review*, v. 96, no. 1, pp. 228-229, October 1, 1954

The structure in Pb at 1.4°K was studied by placing thin magnetic tape in an appropriate place (between two hemispheres or at a pole of the compound sphere), applying a magnetic field of about  $0.8H_c$  normal to the diametrical gap, removing the field and warming up. The tape retains a memory of the magnetic pattern of the field when it was applied and this pattern is revealed by applying ferromagnetic powder. Preliminary results show a structure of scale about 0.5 mm for a sphere of radius 6 mm. (PA, v. 58, #964)

### 390. THE TRANSITION INTO THE INTERMEDIATE STATE OF HOLLOW SUPERCONDUCTING CYLINDERS

Serin, B., Gittleman, J., Lynton, E. A.

*Physical Review*, v. 92, pp. 566-568, November 1, 1953

The transition from the superconducting to the intermediate state has been investigated for hollow tin cylinders with various ratios of inner to outer radii. Thermodynamic arguments show that for values of this ratio greater than  $(2\frac{1}{2}/2)$  the free energy in the normal state becomes less than that in the superconducting state at applied fields less than one-half the critical field. The experimental results indeed show that for ratios of inner

to outer radii greater than  $(2\frac{1}{2}/2)$  the intermediate state begins to appear less than one-half the critical field, whereas, for smaller ratios the intermediate field appears at one-half the critical field. (PA, v. 57, #1335)

### 391. THE ISOTOPE EFFECT IN SUPERCONDUCTIVITY. II. TIN AND LEAD

Serin, B., Reynolds, C. A., Lohman, C.

*Physical Review*, v. 86, pp. 162-164, April 15, 1952

The critical magnetic fields,  $H_c$ , of various isotopic mixtures of Sn and of Pb have been measured as a function of temperature,  $T$ . For tin, the critical temperature  $T_c$  at zero field, is related to the average mass number  $M$  by the relation  $M^{3.46}T_c = \text{const}$ . The critical magnetic fields,  $H_{c0}$ , at absolute zero are proportional to the critical temperatures. The normalized values of critical field,  $H/H_{c0}$ , are the same function of the variable  $T/T_c$  for all the isotopes. An analytic expression for this function giving the best fit to the experimental data is given. The measurements on Pb were made in the temperature range 1.6°K to 4.2°K. The data clearly indicate that the isotope effect is present in this superconductor. (PA, v. 55, #5126)

### 392. IRREVERSIBILITY IN THE SUPERCONDUCTING TRANSITION OF LEAD

Shaw, R. W.

Physics Dept., University of Illinois,  
TR-18, June 1959

The nature of the hysteresis in the magnetic superconducting transition of lead reported by Decker, et al has been studied in some detail. Isothermal resistive measurements of the superconducting transition are also reported. They indicate that some superconducting phase persists in lead to fields as high as three or four hundred gauss above  $H_c$ . Increasing the temperature or measuring current forces the resistive transition back toward  $H_c$ . In general, the hysteresis width and persistence of superconductivity to high fields appear to be closely related. Two methods have been employed to produce the hysteresis in nearly reversible samples; addition of impurities and, more extensively, low temperature plastic strain.

### 393. SOME PROPERTIES OF SUPERCONDUCTORS BELOW 1°K. III. Zr, Hf, Cd, and Ti

Smith, T. S., Daunt, J. G.

*Physical Review*, v. 88, pp. 1172-1176, December 1, 1952

and V. The zero-field transitions and critical field curve for Sn agree well with previous determinations. The V was found to have broad transitions in zero magnetic field and critical field slopes of over 4,000 gauss/deg. The critical field curve of the V was verified by measurements with a susceptibility balance. (PA, v. 52, #6210)

#### 402. ELECTROMAGNETIC INDUCTION IN A SUPERCONDUCTOR

Wexler, A., Corak, W. S.

Letter in *Physical Review*, v. 76, pp. 432-433, August 1, 1949

The e.m.f. between the axis and periphery of a Pb sphere rotating in a vertical magnetic field  $H$  was measured both for varying  $H$  at constant  $T$  and for lowering  $T$  at constant  $H$ . The e.m.f. had its expected value in the normal state, contrary to a previously reported result (Houston and Squire, *Science*, v. 109, p. 439, 1949), but in agreement with the Meissner effect there was no e.m.f. (PA, v. 53, #2464)

#### 403. SUPERCONDUCTIVITY OF VANADIUM

Wexler, A., Corak, W. S.

*Physical Review*, v. 85, pp. 85-90, 1952

The presence of small quantities of O and N in interstitial positions in the V lattice affects markedly the superconductive properties of the metal. X-ray evidence supports the supposition that these impurities set up internal strains which are known to give rise to properties very similar to those of the hard superconductors. It is suggested that these strains, which, unlike those arising from mech. work, are not always removable by vacuum heat-treatment, are responsible for the difficulties assocd. with the prepn. of samples of the metals exhibiting a reversible B, H curve. The sharp penetration fields for a relatively pure specimen are probably not very different from the equil. fields. The transition temp. of V is  $5.13^\circ\text{K}$  ( $dH_c/dT$ )  $T_c = 436 \pm 20$  oersteds/deg, and the Sommerfeld  $\gamma = 15 \times 10^{-4}$  cal/mole deg. (CA, v. 46, 4303h)

#### 404. LITERATURE SURVEY ON THE LOW TEMPERATURE PROPERTIES OF METALS

White, A. E., Siebert, C. A.

J. W. Edwards Bros., Ann Arbor, 1947

#### 405. PROPERTIES OF SUPERCONDUCTING FILMS OF THALLIUM AND INDIUM

Zavaritskii, N. V.

*Doklady Akademii Nauk*, SSSR, v. 85, pp. 749-752, 1952

In films of Tl and In of thickness varying from  $1.7 \times 10^{-4}$  to  $3.6 \times 10^{-6}$  cm. the temp. interval in which the normal elec. resistance  $R_n$  fell to zero does not exceed  $0.02^\circ$ . The crit. temp.  $T_c$  of supercond. lies in the Tl films in the range  $2.29-2.39^\circ\text{K}$ , and in In films, within  $3.39-3.42^\circ\text{K}$ . There is no relation between  $T_c$  and the thickness. Curves of the crit. magnetic field  $H_c$  (at which the resistance becomes  $= R_n/2$  with increasing  $H$ ) of Tl films thicker than  $2.7 \times 10^{-5}$  cm, as a function of  $\Delta T = T_c - T$  show a break; to its left (swell  $\Delta T$ ),  $H_c$  is proportional to  $(\Delta T)^{1/2}$ , and to its right the dependence of  $H_c$  on  $\Delta T$  draws close to that value for the massive metal. The break is even more pronounced on the  $H_c(\Delta T)$  plots for In. In films thinner than  $2.7 \times 10^{-5}$  cm the transition from the superconductive into the normal state and vice versa takes place at the same  $H$ . In thicker films the transition is reversible only close to  $T_c$ , but at larger  $\Delta T$  there is a hysteresis, with the disturbance of the supercond. occurring at a higher  $H$  than its restoration. Thus, in Tl and In, as in Sn, the effect of a change of the  $H_c(\Delta T)$  dependence, and hysteresis, are correlated. The ratio  $H_c/H_{cm}$  of the  $H_c$  of a thin film and of the massive metal being theoretically proportional to  $\delta_0(T)/d$ , where  $\delta_0(T)$  is the depth of penetration of supercond. and  $d$  the thickness, it is possible to det.  $\delta_0(T)$  from the temp. dependence of  $H_c$  and  $H_{cm}$ . Close to  $T_c$ , this dependence is  $\delta_0(T) = \delta_{00}(T - T)^{1/2}$ . From  $\delta_0(T)$  detd. for thin films, the dependence  $H_c/H_{cm} = f[\delta_0(T)/\delta_{00}d]$  can be detd. also for thicker films. These detns. reveal, for thicker films, the existence of 2 transition fields, one  $H_c$ , corresponding to the transition from the superconductive to the normal state, the other to the reverse transition. This is tantamount to the existence of a range in which the normal phase coexists, in an under-cooled metastable state, with the superconducting phase. The value of  $H_c$  is the same for samples of different thicknesses, and evidently corresponds to thermodynamic equil. of the phases; the hysteresis measures the width of the range of the metastable coexistence. From the dependence of  $H_c$  on  $d$ , the values of the const.  $10^6 \delta_{00}$  (cm deg  $^{-1/2}$ ) is, for Tl  $9.2 \pm 0.5$ , In  $5.7 \pm 0.3$ , Sn  $6.5 \pm 0.5$ . The values of the const.  $k$  in the relation  $H_c/H_{cm} = 1 + k(\delta_0/d)$ , valid for thicker films, are Tl  $2.2 \pm 0.5$ , In  $1.5 \pm 0.1$ , Sn  $1.5 \pm 0.3$ . (CA, v. 47, 367c)

#### 406. PROPERTIES OF THIN LAYERS OF SUPERCONDUCTING METALS

Zavaritskii, N.

*Doklady Akademii Nauk, SSSR*, v. 82, pp. 229-231, 1952; v. 9, p. 255, 1939

The superconducting properties of thin layers of Sn and Ta were studied. The thin films were prepd. at 2°K to avoid metal creep. The crit. temp.  $T_c$  remains const. for thicknesses from 1 to 0.01-0.02. As the thickness is further decreased, the  $T_c$  shifts toward lower temp. The min. thickness at which supercond. was observed was  $1.1 \times 10^{-7}$  cm for Sn and  $4 \times 10^{-7}$  cm for Ta. (CA, v. 49, 4356h<sup>2</sup>)

#### 407. THE SUPERCONDUCTING PROPERTIES OF FILMS OF THALLIUM AND TIN CONDENSED AT LOW TEMPERATURES

Zavaritskii, N. V.

*Doklady Akademii Nauk, SSSR*, v. 86, pp. 501-504, 1952

The properties were studied of films of Tl and Sn (thickness from several microns to  $2 \times 10^{-6}$  cm) that were condensed at 80° and 2°K. The crit. temp. ( $T_k$ ) of films condensed at low temperature varied significantly from the usual value of  $T_k$ . For Sn the usual value of  $T_k$  is 3.72°K. For films condensed at 80°K  $T_k = 4.05$  and at 20°K  $T_k = 4.6$ . The corresponding values for Tl are 2.40, 2.5, and 2.9°K. For films condensed at 2°K the film thickness had no effect on  $T_k$ , but for films condensed at 80°K  $T_k$  increased continuously as the thickness was decreased below  $10^{-5}$  cm. The observed differences are attributed to structural changes in the metal films. (CA, v. 49, 14400g)

#### 408. STUDIES OF COMPOUNDS FOR SUPERCONDUCTIVITY

Ziegler, W. T., Young, R. A.

November 28, 1951

Powdered Ti, V, Zr, Ta, and W carbides; Zr, Nb, Ta, W, Mo, Ti, and Th borides; La, Ce, and Nb nitrides; and  $\text{LaH}_{2.45}$  were examined for superconductivity down to 1.8°K by the magnetic method of Horn and Ziegler (*Journal of the American Chemical Society*, v. 69, p. 2762, 1947). Specimens were characterized by X-ray diffraction and/or chemical analysis. Only NbN showed superconductivity; the range, 14.6 to 16.8°K, agreed with that

obtained by Cook, Zemansky and Boorse (*Physical Review*, v. 79, p. 1012, 1950) and others with the electrical resistance or magnetic induction methods. The failure of Ti and V carbides to show superconductivity confirmed the results of Meissner and others (*Zeitschrift für Physik*, v. 65, p. 30, 1930, and v. 75, p. 521, 1932), who used an electrical resistance method. Data for Ta and Nb borides were in agreement with those reported by Hulm and Matthias (*Physical Review*, v. 82, p. 273, 1951) who used a magnetic method. Particle sized measurements of carbide and boride powders indicated that magnetic field penetration should have no effect on the accuracy of the method if a penetration depth of  $1 \times 10^{-5}$  cm is assumed. A physical distribution of superconducting impurities of undermined composition was suggested to account for the superconductivity observed in ZrC, TaC, WC, MoB, and ZrB<sub>2</sub> by other investigators (presented in part at the Oxford Conference on Low Temperature Physics, Oxford, England, August 22-28, 1951). (NRS Abstract) (NSA, v. 6, #2104)

#### 409. STRUCTURES OF SUPERCONDUCTORS.

##### IV. X-RAY AND METALLOGRAPHIC INVESTIGATIONS ON THE SYSTEM BISMUTH-PALLADIUM

Zhuralev, N. N., Zhdanov, G. S.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 25, pp. 485-490, 1953

X-ray and metallographic studies (etching by  $\text{KI} + \text{I}_2$ , concd. or 70%  $\text{HNO}_3$ ) on the system Bi-Pd (from 0 to 100% of either one) prepd. by heating the metals together in quartz ampules *in vacuo* or in argon or He gas at temps. of 1000°, in a resist, or at  $> 1000^\circ$  in a high-frequency oven. The existence of several compds. is indicated. The supercond. is related to the low symmetry and to the complex at. structure. Below 20.33 wt % Pd, the alloy consists of crystals of Bi<sub>2</sub>Pd in a Bi<sub>2</sub>Pd-Bi soln.; from 20.33 to 33.78 wt % Pd, the 2 cryst. phases Bi<sub>2</sub>Pd and BiPd are found side by side. Other compds. are found at 43.5, 51.0 and 60.5 wt % corresponding to Bi<sub>2</sub>Pd<sub>3</sub>, BiPd<sub>2</sub>, and BiPd<sub>3</sub>.  $\alpha$  - Bi<sub>2</sub>Pd has a d. of 11.58, microhardness 170 kg/sq/mm, monoclinic,  $C_{2h} - 2/m$ ,  $a = 12.6$ ,  $b = 4.0$ ,  $c = 5.8$  Å,  $\beta = 102^\circ$ ,  $Z = 4$ ;  $\beta$  - Bi<sub>2</sub>Pd, d. 11.87, microhardness 135, tetragonal,  $D_{4h}^{17} - 14/mmm$ ,  $a = b = 3.362$ ,  $c = 12.983$  Å,  $Z = 2$ ; BiPd, d. 12.54, microhardness 200, rhombic  $D_{2h} - mmm$ ,  $a = 10.8$ ,  $b = 8.6$ ,  $c = 7.2$  Å,  $Z = 16$ .

#### V. X-RAY INVESTIGATION OF THE STRUCTURE OF BiPd

Kheiker, B. M., Zhdanov, G. S., Zhuravlev, N. N.  
*Ibid.*, pp. 621-627

BiPd crystals of approx. 1 mm. length were studied by K radiation from Mo, Co, and Cu, and L radiation from Bi. BiPd crystals are rhombic,  $a = 7.203$ ,  $b = 8.707$ ,  $c = 10.662 \pm 0.002$  Å, point group  $D_{2h} - mmm$ , space group, noncentrosymmetric,  $C_{2v}^{12} = Ccm2_1$  d. 12.56 g./cc., 32 atoms per unit cell. BiPd possesses a structure without a center of symmetry though it nevertheless exhibits supercond.

#### VI. X-RAY INVESTIGATION OF THE STRUCTURE OF THE LOW-TEMPERATURE MODIFICATION OF Bi<sub>2</sub>Pd

Zevin, L. S., Zhdanov, G. S., Zhuravlev, N. N.  
*Ibid.*, pp. 751-754

A detailed analysis of the x-ray spectra of Bi-Pd alloys indicates that the elementary cell of  $\alpha$  - Bi-Pd has the dimensions  $a = 12.74 \pm 0.01$ ;  $b = 4.25 \pm 0.02$ ;  $c = 5.665 \pm 0.005$  Å;  $\beta = 102^\circ 35' \pm 10'$ . The space-group is  $C_2/m$ ; x-ray d. = 11.65 g./cc. The unit cell is sym. about (001) and contains 12 atoms of Bi + Pd in 4 puckered layers, whereas, the layers of  $\beta$  - Bi<sub>2</sub>Pd are planar, space group  $F_4/mmm$ ,  $\beta = 90^\circ$ , d = 11.88 (see also Abstract 426). (CA, v. 49, 4349f-i)

#### D. Penetration Depth

##### 410. THE TIN SURFACE RESISTANCE IN THE SUPERCONDUCTING STATE AT FREQUENCIES OF $7.3 \times 10^{10}$ HERTZ

Bezuglyi, P. A., Galkin, A. A., Levin, G. Ya.  
*Doklady Akademii Nauk, SSSR*, v. 105, pp. 683-684, 1955

The temp. changes of  $R_s/R_n$  of Sn (where  $R_s$  and  $R_n$  are the Sn surface resistance in the supercooled and the normal states) show that at high electromagnetic field frequencies the differences between  $R_s$  and  $R_n$  should disappear, and that such crit. frequency, found by extrapolation, is around  $10^{11}$  Mc. Measurements at such frequencies required some changes in the app., but measurements at  $7.3 \times 10^{10}$  Mc confirmed the conclusion, which can be explained by a rise in the effective penetration depth. (CA, v. 50, 9139 i)

##### 411. PENETRATION DEPTH IN IMPURE SUPERCONDUCTING TIN

Chambers, R. G.

*Proceedings of the Cambridge Philosophical Society*, v. 52, pp. 363-375, 1956

A new method for measuring the surface impedance of metals at low temps. and at radio-frequencies is described. The surface impedance of normal Sn and the penetration depth,  $\lambda$ , in super-conducting Sn were studied at about 9 Mc. frequency as a function of In impurity content. The measured surface impedances agree well with the values expected and the  $\lambda$  values increase with impurity content in confirmation of previous results at 9400 Mc. The variation of  $\lambda$  with the reduced temp.,  $t$ , is well represented by the equation  $\lambda/\lambda_0 = (1 - t^4)^{-1/2}$  in both impure and pure Sn. The abs. value of  $\lambda_0$  found for pure Sn is about  $4 \times 10^{-6}$  cm, significantly lower than previous values. (CA, v. 51, 2381d)

##### 412. TEMPERATURE DEPENDENCE OF PENETRATION DEPTH OF A MAGNETIC FIELD IN SUPERCONDUCTORS

Daunt, J. G., Miller, A. R., Pippard, A. B., Shoenberg, D.

*Letter in Physical Review*, v. 74, p. 842, October 1, 1948

It is pointed out that the Hg colloid experiments of Shoenberg indicate a law  $[\lambda(0)/\lambda(T)]^2 = 1 - (T/T_c)^4$  for the variation with temp.  $T$  of the penetration depth  $\lambda$  of a magnetic field into a superconductor of transition temp.  $T_c$ . More recent experiments provide no strong evidence either for or against this law. (PA, v. 52, #3996)

##### 413. PENETRATION OF MAGNETIC FIELD INTO SUPERCONDUCTORS. I. MEASUREMENTS OF THIN CYLINDERS

Désirant, M., Shoenberg, D.

*Proceedings of the Physical Society, London*, v. 60, pp. 413-424, May 1948

Absolute values of the penetration depth,  $\lambda$  at different temperatures can be obtained from the relative values indicated by measurements on colloids, if  $\Delta\lambda$ , the difference between  $\lambda$  at a variable and at a fixed temperature, is known. Various methods of measuring  $\Delta\lambda$  are reviewed, and an account is given of one particular method in which  $\Delta\lambda$  is deduced from the changes of susceptibility of thin

cylinders with temperature. The changes found for Hg cylinders were, within experimental error, inversely proportional to the radii as simple theory demands, and the temperature variation was consistent with that to be expected from colloid results. The absolute value of  $\lambda$  at 0°K is estimated as  $7.6 \times 10^{-6}$  cm. In the case of Sn the values of  $\Delta\lambda$  measured by the recent method were in rough agreement with those of other methods, but since no colloid results were available, the absolute value of  $\lambda$  remains undetermined. The Hg results are discussed also in relation to critical field measurement on thin films. Some preliminary results bearing on the possible dependence of  $\lambda$  on the magnetic field are mentioned. It is concluded that  $\lambda$  does not vary appreciably in fields up to half the critical value. (PA, v. 51, #2471)

**414. THE PENETRATION DEPTH AND HIGH-FREQUENCY RESISTANCE OF SUPERCONDUCTING ALUMINUM**

Faber, T. E., Pippard, A. B.

*Proceedings of the Royal Society of London, Series A*, v. 231, pp. 336-354, September 6, 1955

Measurements have been made of the surface resistance and reactance of superconducting aluminum, at a frequency of 1200 Mc/s. From the measurements the magnitude of the penetration depth has been deduced. There is evidence that it may be highly anisotropic, but its average value at 0°K may be taken to be  $4.9 \times 10^{-6}$  cm, which is close to the value found previously for tin. This result cannot be explained by the phenomenological theory of London and London (1935) without introducing as an ad hoc hypothesis a dimensionless parameter supposed to vary widely between the two metals. It is shown that the alternative non-local theory due to Pippard (1953) is not open to the same objection. The high-frequency resistance  $R$  of superconducting aluminum has been found to vary with reduced temperature  $t$  in a way similar to that of tin. Reasons are given for believing that the similarity is even more extensive, and that the reduced resistance  $r (= R/R_n)$  is a universal function of two dimensionless quantities,  $t$  and  $\omega/\omega_c$ , for all metals at all frequencies; the characteristic frequency  $\omega_c$  is given approximately by the quantum condition  $\eta\omega_c = kT_c$ . The significance of this result is discussed, and two suggestions are offered as to what modifications to the conventional two-fluid model may be needed in order to explain the exact nature of the func-

tion. The surface resistance and reactance have also been measured for aluminum in the normal state; their ratio is in good agreement with the theoretical value. (PA, v. 58, #8780)

**415. SIZE EFFECTS IN THE SUPERCONDUCTIVITY OF CADMIUM**

Hein, R. A., Steele, M. C.

*Physical Review*, v. 105, pp. 877-822, 1957

Measurement of magnetic threshold fields for Cd of varying specimen size is described and discussed, especially as regards penetration depth. (CA, v. 51, 11047)

**416. APPARATUS FOR THE CONDENSATION OF METALS AT LOW TEMPERATURES. SOME RESULTS ON THE SUPERCONDUCTIVITY OF TIN**

van Itterbeek, A., de Greve, L.

*Bulletin de l'institut international du froid, Annexe* 1955, v. 2, pp. 175-183, 1955

Reference is made to previous work (CA, v. 44, 5174h, v. 48, 4903d). A novel app. for producing thin Sn films at liquid-air temps. is described. Moreover, this app. allows transfer of these films in their state as they are formed. The thickness of the layers is detd. by weighing and is of the same order of magnitude as the penetration of the magnetic field into the superconducting metal. The first deposits are produced by cathodic sputtering in a Ne or A atm., the target being at room temp. The transition point is slightly higher than for the normal metal and lies at 3.65°K for very thin films and at 4°K for thicker ones. Transitions as a function of the magnetic field were studied systematically, and the results are represented in graphs. The curves show unexpected behavior due to the amorphous state of the Sn films. Other expt. were made with thermally vaporized Sn and with low-temp. targets. Deposits formed at low temps. always suffer a recryst. at reheating, provoking an irreversible decrease of resistivity. The transition point is generally higher than 4.2°K. The app. is represented in a diagram. It can be transported from the high-vacuum pumping system to the magnetic cryostat, where the film support can be detached from the liquid-air container and pushed downward into the cryostat which is filled with liquid He. The targets receiving the film are of glass. (CA, v. 49, 14409h)

#### 417. MEASUREMENT OF PENETRATION DEPTH IN HOLLOW SUPERCONDUCTORS

Jaggi, R., Sommerhalder, R.

*Helvetica Physica Acta*, v. 31, pp. 292-293, 1958

Films of Sn or In, 1500 Å in thickness, were deposited on glass or German silver tubes of 0.6 cm radius. A homogeneous magnetic field,  $H_a$ , of 0.1 gauss and frequency of 60 cycles/sec was applied and the resulting field  $H_i$  within the cylinders was measured. At 2.17°K,  $H_i/H_a = 2.2 \times 10^{-5}$  and the extrapolated penetration depth at 0°K was  $\sim 1000$  Å. (CA, v. 53, 3891f)

#### 418. PENETRATION OF MAGNETIC FIELD INTO SUPERCONDUCTORS. II. MEASUREMENTS BY THE CASIMIR METHOD

Laurmann, E., Shoenberg, D.

*Proceedings of the Royal Society of London*,

Series A, v. 198, pp. 560-581, September 7, 1949

The changes with temp. of penetration of a magnetic field into superconducting Sn and Hg were studied by a method due to Casimir in which a mutual inductance with a superconducting core is measured using low-frequency currents. The results were found to be very sensitive to surface conditions, but single crystals with smooth surfaces gave reproducible measurements of  $\lambda(T) - \lambda(2.17^\circ\text{K})$  as a function of temp.  $T$ . These were consistent with the formula  $\lambda(T) = \lambda_0 [1 - (T/T_c)^4]^{-1/2}$ , where  $T_c$  is the transition temp., and  $\lambda_0$  was found to be  $5.2 \times 10^{-6}$  cm for Sn and  $4.3 \times 10^{-6}$  cm for Hg. For Sn there was no significant difference between the values of  $\lambda_0$  for current flow in different crystal directions, though a difference of up to 20% is not excluded. For Hg there is a suggestion that  $\lambda_0$  is about 20% higher for current flow perp. to the principal axis than it is for current flow parallel to the principal axis, but this difference is little more than might be due to experimental errors. There was no evidence for any dependence of  $\lambda$  on a steady magnetic field  $H$ , though an increase of 10% up to 80% of the critical field is not excluded. (PA, v. 52, #7023)

#### 419. PENETRATION OF MAGNETIC FIELD INTO SUPERCONDUCTORS

Laurmann, E., Shoenberg, D. S.

*Nature*, v. 160, pp. 747-748, November 29, 1947

The variation with temperature was measured by observing the mutual inductance of two coils wound on

a massive superconducting core as temperature was lowered (PA #3155, 1946). The expected variation was found for both Hg and Sn, agreeing with other measurements (PA #1526, 1947) in the case of Sn. For Sn some variation was found, which was attributed to a dependence of penetration depth on direction of current flow relative to the crystal axes. (PA, v. 51, #973)

#### 420. PENETRATION OF MAGNETIC FIELDS INTO SUPERCONDUCTORS. III. MEASUREMENTS ON THIN FILMS OF TIN, LEAD AND INDIUM

Lock, J. M.

*Proceedings of the Royal Society of London*,

Series A, v. 208, pp. 391-408, September 7, 1951

The magnetic moments of thin superconducting films obtained by evaporation of the metal in vacuo, have been measured by a ballistic method. Values of the penetration depth,  $\lambda_0$ , at absolute zero, derived from them by extrapolation, are estimated as  $5.0 \pm 0.1 \times 10^{-6}$  cm for Sn,  $3.9 \pm 0.3 \times 10^{-6}$  cm for Pb and  $6.4 \pm 0.3$  cm for In. Within the limits of experimental error the results agree with the penetration law of London and London. From the areas of the magnetization curves, estimates of the difference in surface energy ( $\alpha_n - \alpha_s$ ) per unit area between free surfaces of the normal and superconducting phases respectively are derived, which are smaller than those previously assumed. No evidence is found for an increase in penetration depth at low temperatures and high fields such as that suggested by the theories of Heisenberg and Koppe. (PA, v. 54, #7909)

#### 421. SURFACE PHENOMENA IN SUPERCONDUCTORS IN THE TRANSITION STATE

Meshkovskii, A., Shal'nikov, A.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 17, pp. 851-861, 1947

The distributions of the magnetic field  $H_s$  on the surface of a 30-mm-diam. single-crystal sphere of purest Sn, and on a sphere of polycryst. Sn were detd. by means of a Bi-ribbon micro-explorator, as a function of the external field  $H$ . With a fixed explorator, the usual const.  $H_s$  portion is found on the equator of the sphere, corresponding to the crit. field  $H_c$ , but the pole and the 39th parallel show sharp deviations from the curves corresponding to a homogeneous state. By the pole curve, the superconducting state is preserved over almost  $\frac{1}{2}$  of the transition-state range; persistence of superconducting regions is also

shown by the curve of the 39th parallel. With the explorer moved along the surface of the monocryst. Sn sphere, the family of distribution curves of  $H_s$  at the constant temp. of 2.97°K and at decreasing  $H$ , from 101.5 to 0 oersted, corresponding to fractions  $x_n$  of the normal phase from 1 to zero, shows early deviations from the behavior predicted on the common assumption that the superconductive and the normal phase do not reach the surface but become lost as a result of branching. These deviations become noticeable at  $x_n = 0.94$ , and they increase with further increasing  $x_n$ , i.e., with decreasing  $H$ ; at  $x_n = 0.13$ ,  $H = 72.5$ , the width of superconducting areas on the surface attains several mm. At  $H = 68$  and 62 oersteds where, theoretically,  $x_n = 0$ , there still remain inclusions of the normal phase, the persistence of which can be described as a superconductive "undercooling" effect. Sharp nonhomogeneity of  $H_s$  in the transition is shown also by the family of distribution curves taken at const.  $H = 100$  oersteds and temps. varying from 2.72°K ( $x_n = 0.22$ ) down to 2.32°K ( $x_n = 0$ ). These curves show the same "undercooling" phenomenon. The conclusion that the superconductive phase heterogeneity does reach the surface is consistent only with the assumption of a nonequil. superconductive transition, or that the normal phase at the surface is "undercooled." These conclusions hold at a sufficient distance ( $\sim 0.5^\circ$ ) from the crit. temp.  $T_c$ , and may have to be modified at as close as 0.01–0.02° below  $T_c$ , where the depth of penetration is of the order of  $10^{-4}$  cm, i.e., about 10 times as great as at lower temps. (CA, v. 44, 2809g)

**422. THE PENETRATION DEPTH OF MAGNETIC FIELDS IN SUPERCONDUCTORS AND ABSORPTION IN METALS**

Möglich, F., Rompe, R.

*Annalen der Physik*, Leipzig (Series 6), v. 4, no. 6, pp. 335–351, 1949 (in German)

A connection is established between the penetration depth and an absorption edge in the short-wave part of the visible region. The absorption in question is of the type discovered by Wolter (*Zeitschrift für Physik*, v. 105, no. 5–6, pp. 269–308, 1937) which occurs in thin metal films and is here ascribed to resonance of the plasma oscillations (Abstract 158). It does not occur in bulk metal because of the hindrance connected with the transfer of both momentum and energy from the electromagnetic waves to the plasma oscillations. For small thicknesses at which this absorption becomes apparent agrees with the

measurements on Ag discussed by Wolter and the position of the edge found by R. Havemann on Hg colloids confirms the relation with the penetration depth. (PA, v. 53, #6506)

**423. INFLUENCE OF A CIRCULAR CLOSED MAGNETIC FIELD ON THE SUPERCONDUCTIVE STATE OF A MONOCRYSTALLINE HOLLOW LEAD CYLINDER**

Nabauer, M.

*Zeitschrift für Physik*, v. 141, pp. 416–444, 1955

A lead single crystal in the shape of a thin-walled hollow cylinder with electropolished surface was provided with toroidal coils for producing a circular magnetic field and for measuring changes in flux. Because of the symmetry of the field, the transition from super to normal conductivity takes place without passing through a complicated intermediate state and is accessible to calculation. The transition in a supercritical field and the time variation of the flux on switching on or off such a field were measured. Further, the change of the penetration depth with field strengths below critical were investigated. It was found that at fields greater than  $H_c/8$  the penetration depth begins to increase. This effect, which shows hysteresis, is ascribed to surface imperfections. It is shown that, according to the London theory, the density of the screening current is increased at the base of a groove, and since the value of this current determines the onset of the transition, the base of a groove will become normal at subcritical fields. (PA, v. 59, #371)

**424. FIELD VARIATION OF THE SUPERCONDUCTING PENETRATION DEPTH**

Pippard, A. B.

*Proceedings of the Royal Society of London*, Series A, v. 203, p. 210, September 22, 1950

The high-frequency technique developed previously (Abstract 174) has been used to investigate the dependence of the penetration depth in superconducting tin on the strength of the applied field. A steady magnetic field was applied transverse to a thin cylindrical specimen forming part of a 3 cm resonator, any resulting change in penetration depth being revealed as a shift in the resonant frequency. The change was greatest close to the transition temperature (3.72°K), but even here it amounted to no more than 3% at the critical field strength. As the temperature was lowered, the effect became

smaller at first, reaching a very low value at 3°K, and then increasing once more to about 2% at 1.7°K. The effect of a steady magnetic field on the high-frequency resistance was also studied, though not in great detail. Above 3°K the resistance decreases slightly until at a field strength rather greater than  $\frac{1}{2}H_c$ , a sudden increase announces the formation of the intermediate state. At lower temperatures the effect of the steady field is to increase the resistance slightly. It is suggested that the very small change in penetration depth even at the critical field strength is evidence of the existence of long-range order in the superconducting state over a distance of  $10^{-4}$  cm or more, and the very sharp resistance transition in pure superconductors is adduced as further evidence of this hypothesis. (PA, v. 53, #8754)

**425. AN EXPERIMENTAL AND THEORETICAL STUDY OF THE RELATION BETWEEN MAGNETIC FIELD AND CURRENT IN A SUPERCONDUCTOR**

Pippard, A. B.

*Proceedings of the Royal Society of London, Series A*, v. 216, pp. 547-568, February 24, 1953

The penetration depth  $\lambda$ , in superconducting tin at 0°K has been found to be capable of variation by the addition of impurity, 3% of indium causing it to be nearly doubled, although the thermodynamical properties such as  $T_c$  are hardly affected. It is suggested that this result throws doubt on the phenomenological theory of F. and H. London, and a new equation for the supercurrent is proposed, in which the current is related to an average of the vector potential over a region around the point considered. The size of the region is governed by a parameter  $\xi$ , which is dependent, in a similar way to the mean free path in a normal metal, on the degree of purity. The new theory agrees in a satisfactory manner with the experimental results, and also provides an explanation of the magnitude of  $\lambda$  in a pure metal. It has been found that the unusual anisotropy of  $\lambda$  in pure tin is absent in tin + 3% indium, and this too is in agreement with the prediction of the new theory. The fact that the temperature variation of  $\lambda$  appears to have the same form independent of the degree of purity implies that  $\xi$  depends on temperature in the same way as  $\lambda$ ; this result agrees with the observed behavior of the interphase surface energy,  $a_{ns}$ , if  $\xi$  is regarded as determining the width of the interface between superconducting and normal regions. The paper concludes with a discussion of the relation of the

new theory to microscopic theories of superconductivity. (PA, v. 56, #4106)

**426. EFFECT OF THE ENERGY GAP ON THE PENETRATION DEPTH OF SUPERCONDUCTORS**

Schawlow, A. L., Devlin, G. E.

*Physical Review*, v. 113, no. 1, pp. 120-126, January 1, 1959

The dependence on temperature of the penetration depth of superconducting tin crystals was measured by a new low-frequency (100 kc/s) method. The sample served as the core of a solenoid whose inductance changed with the penetration depth. The inductance controlled the frequency of an oscillator which was measured precisely. It is found that there are departures from the law  $\lambda = \lambda_0 [1 - (T/T_c)^4]^{1/2}$  derived from the Gorter-Casimir two-fluid theory. The departures are shown to arise from an energy gap in the spectrum of electron excitations and are qualitatively like those predicted by Lewis' extension of the two-fluid model to include a gap. Throughout the temperature range from 1.8 to 3.69°K the measured penetration depths agree well with the theory of Bardeen, Cooper, and Schrieffer. (PA, v. 62, #4621)

**427. INVESTIGATION ON THE DEPTH OF PENETRATION OF A MAGNETIC FIELD IN A MASSIVE SUPERCONDUCTOR**

Shal'nikov, A. I., Sharvin, Y. V.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 18, pp. 102-103, 1948 (CA, v. 46, 2356h)

The sample was pure tin contg. less than 0.002% impurities, with the surface polished and vacuum-treated; field strengths were from 0.44 to 49.8 oersteds, and temps. from 3.1 to 3.704°K. The magnetic field penetrated into the sample to a depth of from 1.87 to  $10.3 \times 10^{-5}$  cm. (CA, v. 48, 9772i)

**428. INVESTIGATION OF PENETRATION DEPTH OF A MAGNETIC FIELD INTO A MASSIVE SUPERCONDUCTOR II.**

Sharvin, Yu. V.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 22, pp. 367-375, no. 3, 1952 (in Russian)

Using the method described in the preceding abstract, the temperature derivative  $\partial\lambda/\partial T$  of penetration depth

has been studied for two tin specimens whose surfaces were more perfect than that used in Part I. The method of oscillating the temperature was also modified, this time being based on a periodic illumination of the thermally isolated specimen. In the neighborhood of  $T_c$  the result  $\lambda = 4.6 \times 10^{-6} (T_c - T)^{-1/2}$  cm was found for small fields  $H$ , while the effect of the field was found to be given by  $\partial\lambda/\partial T = (\partial\lambda/\partial T) H = 0 [1 + \alpha (H/H_c)^2]$ , with  $\alpha = 0.29$ . The result for small  $H$  agrees well with data of Laurmann and Shoenberg though slight discordances appear at lower temperatures; the higher values of  $\lambda$  found earlier are attributed to poor surface conditions. The value of  $\alpha$  is, however, much higher than found by Pippard (Abstract 424) and also than predicted by the theory of Ginzburg and Landau (Abstract 89). (PA, v. 55, #7299)

**429. MAGNETIC FIELD DEPENDENCE OF HIGH-FREQUENCY PENETRATION INTO A SUPERCONDUCTOR**

Spiewak, M.

*Physical Review Letters*, v. 1, pp. 136-138, 1958

For superconducting Sn and In, surface reactance decreases anomalously with increasing static magnetic field. (CA, v. 52, 1797d)

**430. MAGNETIC FIELD PENETRATION IN SUPERCONDUCTING LEAD**

Steele, M. C.

*Physical Review*, v. 78, pp. 791-793, June 15, 1950

The magnetic susceptibility of small superconducting Pb spheres (radius  $\sim 10^{-3}$  cm) has been determined by a self-inductance method. On the basis of relations derived from the London theory for reducing the data, the penetration depth,  $\lambda$ , is calculated for 3 different Pb samples at 4.22°K. Results indicate that  $\lambda$  is  $1.3 \pm 0.3 \times 10^{-5}$  cm at this temperature. In addition, it is found that, within experimental error,  $\lambda$  is not a function of the size of the sphere. It is noted that there is need for using smaller sized particles and accounting for the interaction effects if future colloid investigations designed to test the London theory are to be successful. (PA, v. 53, #7254)

**431. PENETRATION DEPTH OF SUPERCONDUCTORS**

Steele, M. C., Osborne, M. F. M.

Letter in *Physical Review*, v. 91, p. 1281, September 1, 1953

A model of a superconductor in which electrons move in parabolic potential wells gives the relation  $\lambda_0 = 1.6 (hc/eH_0)^{1/2}$  between penetration depth and critical field at 0°K. This relation which, apart from the numerical factor is the same as one proposed by F. London (PA #776, 1945) gives values of  $\lambda_0$  about 2½ times higher than found in the most accurate experiments, but agrees roughly with some less reliable data. (PA, v. 57, #1330)

**432. SUPERCONDUCTIVITY OF INDIUM-THALLIUM SOLID SOLUTIONS**

Stout, J. W., Guttman, L.

*Physical Review*, v. 88, pp. 703-712, 1952

Superconducting properties are reported for In contg. 0-50% Tl. The magnetic induction and the elec. resistance were measured at various temps. and magnetic field strengths. Single-crystal specimens contg. 0, 5, 10, 15, and 20 at. % Tl, and polycryst. specimens contg. 15, 20, 38, and 50% Tl, were investigated. In the more dil. solns. the penetration of field into the specimens at const. temp. was sharp and the restoration of resistance occurred at substantially the same field. As the concn. of Tl increased, the flux penetration occurred over a wider range of field and the resistance appeared only after practically all the flux had penetrated. For the single-crystal specimens the trapped flux in zero field was <20% of that corresponding to unit permeability at the field where flux penetration begins. The breadth of transition in the polycryst. specimens was like that of the single crystals, but the trapped flux was much larger. The crit. fields for destruction of supercond. are given for 0-20% Tl and the electronic heat capacities of the normal metal are calcd. from them. (CA, v. 47, 3068f)

**433. PENETRATION DEPTH, SUSCEPTIBILITY, AND NUCLEAR MAGNETIC RESONANCE IN FINELY DIVIDED SUPERCONDUCTORS**

Tinkham, M.

*Physical Review*, v. 110, no. 1, pp. 26-29, April 1, 1958

On the basis of experimental evidence that the effective superconducting penetration depth is increased by a decrease in electronic mean free path, whether by body or surface scattering, and guided by the Pippard (Abstract 425) nonlocal theory, it is proposed that many types of

experiments on small particles can be interpreted semi-quantitatively by taking over the formal results of the London theory with  $\lambda_0$  modified to  $\lambda_0(1 + \xi_0/l_{eff})^{1/2}$ . In this,  $\xi_0$  is Pippard's coherence length and  $1/l_{eff}$  includes both surface and body scattering. This method gives a good fit to Whitehead's susceptibility data (Abstract 274) on colloidal superconducting mercury, but predicts a narrower nuclear resonance line than is observed by Reif in a similar colloid (Abstract 266, 236). (PA, v. 62, #1481)

#### 434. CRITICAL MAGNETIC FIELDS OF SUPERCONDUCTING TIN FILMS

Zavaritskii, N. V.

*Doklady Akademii Nauk, SSSR*, v. 78, pp. 665-668, no. 4, 1951 (in Russian)

Resistance measurements are described of the critical fields  $h$  of Sn films of thickness,  $d$ ,  $4.4 \times 10^{-6}$  cm to  $1.5 \times 10^{-4}$  cm, evaporated on to glass in high vacuum conditions. The transitions were sharp ( $\sim 0.01^\circ\text{K}$  wide) and the transition temperatures ( $3.75^\circ\text{K}$  to  $3.84^\circ\text{K}$ ) were not much different from those of bulk Sn. For the thicker films the relation  $h/H_c = 1 + 7 \times 10^{-6}/d$  was found for  $T_c - T = 1.3^\circ\text{K}$  ( $H_c$  = critical field of bulk Sn); for the thinner films  $h/H_c$  varied more rapidly as  $d$  is reduced. The results are to be in agreement with the theory of Ginzburg and Landau (Abstract 89); on the basis of this theory values of the penetration depth are deduced which are about 20% higher than those found from experiments on bulk Sn (Abstract 418). (PA, v. 55, #1018)

#### 435. INVESTIGATION OF SUPERCONDUCTING PROPERTIES OF THALLIUM AND TIN FILMS DEPOSITED AT LOW TEMPERATURES

Zavaritskii, N. V.

*Doklady Akademii Nauk, SSSR*, v. 86, no. 3, pp. 501-504, 1952 (in Russian)

Measurements were made of (a) the critical magnetic field, (b) the magnetization curve in a longitudinal field, for thin films ( $2 \times 10^{-6}$  cm to several microns) of tin and thallium deposited on glass at  $2^\circ\text{K}$  and  $80^\circ\text{K}$  in rigorous high vacuum conditions. As found previously the films deposited at  $2^\circ\text{K}$  had much higher critical fields than those annealed at  $300^\circ\text{K}$  or deposited at  $80^\circ\text{K}$ . Although the restoration of resistance took place fairly sharply in both unannealed and annealed films, the magnetic moment measurements showed that in the former, field penetration took place over a wide range of fields and it

is suggested that the transition is really a second order one (as in Abrikosov's "second group of superconductors," Abstract 10). (PA, v. 56, #5476)

#### 436. PROPERTIES OF SUPERCONDUCTING INDIUM AND THALLIUM FILMS

Zavaritskii, N. V.

*Doklady Akademii Nauk, SSSR*, v. 85, no. 4, pp. 749-752, 1952 (in Russian)

Variation of critical field,  $h$ , of these films (deposited at  $300^\circ\text{K}$  or at  $2^\circ\text{K}$  and annealed at  $300^\circ\text{K}$ ) with thickness,  $d$  ( $1.7 \times 10^{-4}$  to  $3.6 \times 10^{-6}$  cm), and temperature was similar to that found earlier for tin (Abstract 1018), and the transition temperatures were very close to those of the bulk metals. The penetration depth  $\lambda$  was deduced from the relation  $h/H_c = \sqrt{6\lambda/d}$  applied to the thinnest films and for indium agreed with Lock's value (Abstract 420); the temperature variation agreed with that given by Daunt, Miller, Pippard and Shoenberg (Abstract 412). For the thicker films the relation  $h/H_c = 1 + k\lambda/d$  was found with  $k = 2.2 \pm 0.1$  for In (cf.  $1.5 \pm 0.3$  for Sn) rather than  $k = 1$  as predicted by the Landau-Ginsburg theory. (PA, v. 56, #7684)

#### 437. THE SUPERCONDUCTIVITY OF LANTHANUM AND CERIUM

Ziegler, W. T.

*Journal of Chemical Physics*, v. 16, p. 838, 1958; cf. CA, v. 42, 1775g

The variation with temp. of the magnetic permeability of La and Ce was detd. La contg. 0.8% Fe became superconducting at  $4.85 \pm 0.15^\circ\text{K}$ . La contg. 0.5-1.0% Al, Si, and W became superconducting at  $4.45 \pm 0.10^\circ\text{K}$ . Ce contg. 2.5% Fe did not become superconducting at  $2^\circ\text{K}$ . A transition of 10% of the material from the normal to the superconducting state could have been detected. The results obtained by other investigators are discussed briefly. (CA, v. 42, 7643i)

#### 438. STUDIES OF COMPOUNDS FOR SUPERCONDUCTIVITY

Ziegler, W. T., Young, R. A.

*Physical Review*, v. 90, pp. 115-120, April 1, 1953

A number of metal carbides, borides, nitrides and a hydride, in the form of powders, have been examined for superconductivity down to  $1.8^\circ\text{K}$  using a magnetic

method. The substances tested were TiC, VC, ZrC, TaC, WC, ZrB, NbB<sub>2</sub>, TaB<sub>2</sub>, WB, MoB, TiB<sub>2</sub>, ThB<sub>2</sub>, LaN, CeN, NbN, and LaH<sub>2.45</sub>. All specimens were characterized by X-ray diffraction methods and, in most instances, by chemical analysis. Of these substances only NbN gave evidence of superconductivity. The results for NbN are in general agreement with the work of others. The results for TiC and VC are in agreement with those found by Meissner et al., using an electrical resistance method, while those for TaB<sub>2</sub>, NbB<sub>2</sub>, WC and WB are in agreement with observations made by Matthias and Hulm using a magnetic method. On the other hand, ZrC, TaC, WC and "zirconium boride" had previously been observed to exhibit superconductivity above 1.8°K by the electrical resistance method. The results for WC and MoB have recently been confirmed by Matthias and Hulm. The substances ThB<sub>2</sub>, LaN, CeN and LaH<sub>2.45</sub> had not previously been examined for superconductivity. Particle size measurements were made on the carbide and boride powders. The particles were large enough for magnetic field penetration effects to have caused no difficulty, if a penetration depth of  $1 \times 10^{-5}$  cm, observed for pure metal, is assumed to apply to the present compounds. The failure to observe superconductivity in the substances ZrC, TaC, WC and MoB in the present study is discussed in terms of a postulated physical distribution of superconducting impurities of undetermined composition which are assumed to account for the superconductivity observed in these compounds by other investigators. (PA, v. 56, #4107)

### E. Energy Gap

#### 439. EXPERIMENTAL EVIDENCE FOR AN ENERGY GAP IN SUPERCONDUCTORS

Biondi, M. A., Forrester, A. T., Garfunkel, M. P., Satterthwaite, C. B.

*Reviews of Modern Physics*, v. 30, no. 4, pp. 1109-1136, October 1958

A critical review of evidence from (a) thermal conductivity, specific heat and critical fields, (b) nuclear resonance and relaxation, and (c) microwave and infrared studies of bulk metal and of thin films. About 80 references. (PA, v. 62, #2354)

#### 440. MILLIMETER WAVE STUDIES OF SUPERCONDUCTING TIN

Biondi, M. A., Forrester, A. T., Garfunkel, M. P.

*Physical Review*, v. 108, pp. 497-498, 1957

Energy gaps determined agree with theory but await

calculation of theoretical absorptivities for more rigorous comparison. (CA, v. 52, 4330a)

#### 441. MEASUREMENT OF THE TEMPERATURE VARIATION OF THE ENERGY GAP IN SUPERCONDUCTING ALUMINUM

Biondi, M. A., Garfunkel, M. P.

*Physical Review Letters*, v. 2, pp. 143-145, 1959

Absorption by superconducting Al of 3.12, 3.36, 3.96, 4.96, 7.37, and 19.05 mm. radiation at 0.38°K was studied. Above 3.96 mm, the intrinsic absorptivity goes to zero at 0°K. For shorter wave lengths appreciable 0°K absorption remains. The implied forbidden energy gap has 3.25/3.52 the theoretical value for reduced temps. of 0°K. (CA, v. 53, 8821h)

#### 442. MICROWAVE MEASUREMENTS OF THE ENERGY GAP IN SUPERCONDUCTING ALUMINUM

Biondi, M. A., Garfunkel, M. P., McCoybrey, A. O.

*Physical Review*, v. 108, no. 2, pp. 495-497, October 15, 1957

Reports measurements on the variation of  $r = R/R_n$  with  $t = T/T_c$  ( $R$  = surface resistance,  $R_n$  = resistance in normal state,  $T_c$  = transition temperature), down to  $t = 0.75$ , at wavelengths between 19 mm ( $h\nu = 0.65kT_c$ ) and 4.06 mm ( $h\nu = 3.04kT_c$ ). At all frequencies,  $r$  starts to fall as soon as  $T$  falls below  $T_c$ , but for  $h\nu \sim kT_c$ , the initial fall is gradual, whereas for  $h\nu > \sim kT_c$ , it is steep. Also, for  $h\nu > \sim kT_c$ , it is found that  $r > r_c$ , where the value of  $r_c$  is calculated theoretically by extrapolation from the low-frequency curves, using a two-fluid model. It is suggested that the additional absorption  $r - r_c$  is due to quantum excitation of electrons across an energy gap  $\Delta E(t)$ , occurring when  $h\nu > \Delta E(t)$ . Hence, from the temperature at which  $(r - r_c)$  vanishes at each frequency, the form of  $\Delta E(t)$  is deduced, and found to agree quite closely with that predicted theoretically by Bardeen, Cooper and Schrieffer. (PA, v. 61, #193)

#### 443. ATOMIC HEATS OF NORMAL AND SUPERCONDUCTING VANADIUM

Corak, W. S., Goodman, B. B., Satterthwaite, C. B., Wexler, A.

*Physical Review*, v. 102, pp. 656-661, 1956

(Cf. following Abstract.) The at. heats of V, in the normal and superconducting states, were detd. from just above the

transition temp.,  $T_c = 5.03^\circ\text{K}$ , down to  $1.1^\circ\text{K}$ . After corrections to the 1948 temp. scale were made, the normal state at. heat could be represented by  $C_n = \gamma T + (12/5)\pi^4 R (T/\theta)^3$ , with  $\gamma = 0.00926 \pm 0.00003$  joule/mole/deg<sup>2</sup>, and  $\theta = 338 \pm 5^\circ\text{K}$ . The entropy difference,  $S_n - S_s$ , between the normal and superconducting states, extrapolated to  $0^\circ\text{K}$  vanished, in accordance with the 3rd law of thermodynamics. The crit. field values deduced from  $S_n - S_s$  gave  $H_0 = 1310$  oersteds; at higher temps. they were in agreement with initial penetration fields previously reported. The most interesting result of this work was that below  $\sim 0.7T_c$  the electronic contribution to the at. heat of the metal in the superconducting state could be represented by an exponential expression of the form  $C_{es}/\gamma T_c = ae^{-bT_c/T}$  with  $a = 9.17$  and  $b = 1.50$ ; such an exponential relation was consistent with a single-electron model of a superconductor which involved a gap of the order of  $kT_c$  per electron in the spectrum of available energy levels. (CA, v. 50, 12636b)

- 444. EXPONENTIAL TEMPERATURE DEPENDENCE OF THE ELECTRONIC SPECIFIC HEAT OF SUPERCONDUCTING VANADIUM**  
Corak, W. S., Goodman, B. B., Satterthwaite, C. B., Wexler, A.  
*Physical Review*, v. 96, pp. 1442-1444, 1954; cf. CA, v. 46, 4303h

The sp. heat of V was measured in the superconducting state from its transition temp.,  $5.05$  to  $1.2^\circ\text{K}$ . The reduced electronic sp. heat  $C_{es}/\gamma T_c$  is plotted against the reciprocal of the reduced temperature,  $T_c/T$ . For  $T_c/T$  values of  $1.0$ - $4.2$ , the data are represented by  $C_{es}/\gamma T_c = ae^{-bT_c/T}$ . Data (unpublished) on V by Worley, Zemansky and Boorse lie on this line. Data for Nb (Brown, Zemansky, and Boorse, CA, v. 46, #5950 h; v. 48, #435 g) and for Sn (Goodman, CA, v. 47, #9076 h are also represented by this equation). In any single model of a superconductor with a gap  $\epsilon$  in the energy-level spectrum, the expression for the sp. heat would be dominated, at sufficiently low temps., by the term  $\exp(-\epsilon/kT)$ . Data for V, Nb and Sn support this concept. The exptl. magnitude of this energy gap is of the order of  $kT_c$ . (CA, v. 49, 3646c)

- 445. ENERGY LOSS OF A CHARGED PARTICLE TRAVERSING SUPERCONDUCTORS**  
Hayakawa, S., Kitao, K.

*Progress of Theoretical Physics*, Japan, v. 16., pp. 131-138, 1956

See also Abstract 421. (CA, v. 51, #4123 f)

- 446. STRUCTURE OF SUPERCONDUCTORS IN THE INTERMEDIATE STATE**

Sharvin, Yu. V., Balashova, B. M.

*Zhurnal Eksperimentalnoi i Teoreticheskoi Fiziki*, v. 23, no. 2 (8), pp. 222-228, 1952 (in Russian)

Using the method devised by Shalnikov in which a long bismuth wire is used to reveal inhomogeneities of magnetic field (based on the nonlinearity of the relation between resistance and field), the homogeneity of field in a narrow gap between two monocrystalline tin hemispheres in the intermediate state was studied. Contrary to observations based on a micro-probe technique, the inhomogeneity found (due to the fine structure of the intermediate state) did not appear to depend on the particular order of variation of field and temperature by which the state concerned was reached. It is suggested that this discrepancy may arise from the technique, which averages the detailed inhomogeneity structure, or may be due to some difference in quality of specimens. (PA, v. 56, #5479)

- 447. ENERGY-GAP INTERPRETATION OF EXPERIMENTS ON INFRARED TRANSMISSION THROUGH SUPERCONDUCTING FILMS**

Tinkham, M.

*Physical Review*, v. 104, pp. 845-846, 1956

A  $0^\circ\text{K}$   $3kT_c$  gap (one-electron energy state) model formalizes a promising interpretative approach. (CA, v. 51, 5538i)

- 448. SUPERCONDUCTING ENERGY GAP INFERENCES FROM THIN-FILM TRANSMISSION DATA**

Tinkham, M.

*Physical Review*, v. 110, pp. 778-779, 1958

Data for Pb and Sn thin-film transmission at superconducting temps. fit the theory of Bardeen, et al (Abstract 34). (CA, v. 52, 16040g)

**PART III. APPLICATIONS****449. SOME ASPECTS OF THE POSSIBLE APPLICATION OF THE GYROSCOPIC AND INERTIAL PROPERTIES OF ELEMENTARY PARTICLES TO THE MEASUREMENT OF ANGULAR VELOCITY**

Astbury, N. F.

April 1957

Royal Aircraft Establishment, Great Britain, Ministry of Supply

TN-EL 140

Three ways in which gyroscopic and inertial properties of elementary particles might be applied as an alternative to conventional gyroscopes in the control and navigation of airborne vehicles are examined: (1) the direct application of atoms or atomic particles; (2) the use of electron beams, and (3) the use of conduction electrons in normal metals or in superconductors.

**450. AN APPLICATION OF SUPERCONDUCTIVITY TO INERTIAL NAVIGATION (U)**

Culver, W. H., Davis, M. H.

January 7, 1957

RAND Corp., RM-1852

Project RAND.

**451. A SENSITIVE SUPERCONDUCTING "CHOPPER" AMPLIFIER**

de Vroomen, A. R., van Baarle, C.

*Physica*, v. 23, no. 8, pp. 785-794, August 1957

A dc chopper amplifier is described, similar to that of Templeton for use where the source impedance is extremely small. The input chopper is a superconducting wire periodically brought into the normal resistive state by an ac magnetic field. The dc sensitivity is better than  $10^{-11}$  v. (PA, v. 61, #4033)